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A STUDY OF GREENALITE*

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I. INTRODUCTION

The mineral greenalite occurs in the Biwabik iron formation of Minnesota. It is an iron silicate and possesses a granular structure akin to that of the cherty iron formations which make up the greater part of the Biwabik. Both composition and structure have suggested that greenalite is a primary mineral from which many of the cherty iron formations or jaspilites were formed. These in turn, by leaching of the silica, have yielded the rich iron deposits of Minnesota.

In the present work it has been found possible to examine in detail only the typical greenalite rock from the Mesabi range containing the original greenalite mineral. The experimental work involved a study of the microscopic, physical, and chemical properties of the type material and also of the important associated minerals. The results tend to confirm Leith's[1] view that greenalite is a definite mineral, distinct from other known mineral species.

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[1] Leith, C. K., The Mesabi Iron-bearing District of Minnesota: Monograph **43,** *U. S. Geol. Survey,* p. 115, 1903.

SUMMARY OF PROPERTIES OF GREENALITE

Greenalite is a pure hydrous ferrous silicate occurring as small greenish rounded granules having a specific gravity of 3.0. It is isotropic and probably amorphous, and is associated with very similar material (herein called metagreenalite) slightly mottled in appearance, occurring as a felt of fine anisotropic green needles. The isotropic mineral has an index of refraction of about 1.675 and a fairly high dispersion. It is moderately magnetic and on heating loses water readily, becoming opaque black and strongly magnetic. Three types of alteration were observed; one to iron oxides on the surface of the specimen, due to ordinary weathering; the second to metagreenalite, apparently through incipient crystallization; and the third to a light colored fibrous mineral by the agency of magnesian waters. This fibrous mineral (herein called mineral *X*) occurs in the rock to the extent of about 40% and is a hydrous metasilicate of ferrous iron, magnesium, and ferric iron. It possesses properties which indicate that it is a new or little known species, and will be reported on in a later paper.

OCCURRENCE AND DISTRIBUTION OF GREENALITE

Greenalite occurs as a primary mineral in some of the iron ranges of the Lake Superior region. This district still remains the only one in which the mineral has been positively identified, although other occurrences of greenalite-like material[2] have been described.

The Biwabik iron-bearing formation of the Mesabi range, in which the mineral greenalite is most extensively developed, is the largest of the Lake Superior iron formations. Its original extent is believed by Gruner[3] to have been from 5,000 to 10,000 square miles in area with an average thickness of 330 feet. This tremendous volume of rock consisted largely of chert. The next most abundant constituents were the iron minerals—greenalite, siderite, and iron oxides. Geologists who have studied the Mesabi range are not entirely in accord with regard to the relative amounts of each of these iron minerals in the original rock. An earlier theory held that greenalite was the only one of importance. More recently, emphasis has been placed on the other iron minerals.

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[2] Moore, E. S., The Iron Formation on Belcher Islands, Hudson Bay, etc.: *Jour. Geol.*, vol. **26**, p. 415, 1918.

[3] Gruner, J. W., Origin of Sedimentary Iron Formations: *Econ. Geol.*, vol. **17**, p. 412, 1922.

At present greenalite is found only in the least altered portions of the Biwabik formation, and as these contain no iron ores they have received little geological examination. The mineral is characteristically associated with slate layers which apparently have acted as protective coatings. Dr. F. F. Grout* states that it is now almost impossible to obtain good samples in place as the pits from which samples were taken some years ago, near Biwabik, Minnesota, are largely filled in.

SUMMARY OF LITERATURE

The composition and properties of greenalite have been studied by Spurr[4] and Leith.[5] The former, though identifying the mineral as glauconite, was the first to point it out as a source mineral for the other iron-bearing rocks of the Mesabi. Leith showed later that the mineral approaches a pure hydrous ferrous silicate in composition unlike any known species, and suggested the name "greenalite." In both of these studies, neither the composition nor the properties of the mineral were determined exactly due to the difficulties of separating pure greenalite. Such values as were obtained differ somewhat from those arrived at in this investigation.

The origin of greenalite was studied experimentally by Leith.[6] He found that alkaline silicates and ferrous salts react to produce a precipitate similar to greenalite in composition and in globular habit. He concluded that natural greenalite might be formed by similar reagents resulting from the action of sea-water on hot submarine basalts. Other conjectures as to the origin of greenalite are: (1) that greenalite represents clastic fragments of a volcanic glass, proposed by N. H. Winchell;[7] (2) that greenalite is an organic precipitate, proposed by Spurr;[8] and (3) that greenalite is a precipitate, deposited from solutions deriving their iron from normal weathering with or without organic materials assisting in the solution and precipitation of iron, and in the diagenetic reduction of ferric compounds, proposed by Leith[9] (but later abandoned by him), and followed by Moore,[10] Gruner,[11] and Gill.[12]

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* Personal Communication to J. E. Hawley.

[4] Spurr, J. E., The Iron-bearing Rocks of the Mesabi Range: *Bull. Geol. Nat. Hist. Survey, Minnesota*, **X**, 1894.

[5] Leith, C. K., *op. cit.* (Monograph **43**), pp. 102–116, 1903.

[6] Leith, C. K. (Van Hise, C. R., and), The Geology of the Lake Superior Region: *U. S. Geol. Survey*, Monograph **52**, pp. 521–529, 1911.

[7] Winchell, N. H., *Geol. Nat. Hist. Survey, Minnesota*, vol. **V**, 1900.

Sketch of the Iron Ores of Minnesota: *Am. Geol.*, vol. **XXIX**, p. 160, 1902.

Saponite, Thalite, Greenalite, Greenstone: *Bull. Geol. Soc. Am.*, vol. **23**, p. 330, 1912.

[8] Spurr, J. E., *op. cit.*, p. 242.

ACKNOWLEDGMENTS

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II. EXPERIMENTAL WORK

The experimental work consisted of a study of the habit, properties, and associations of the mineral greenalite in a specimen of greenalite rock from the Mesabi iron range (from the eastern outskirts of the town of Biwabik, Minnesota, Sec. 2, T. 58 N, R. 16 W). This may be considered a type locality.

A general microscopic examination of greenalite rock served to indicate the minerals present, their modes of occurrence, and some of their optic properties. A complete chemical analysis of the rock was supplemented by a spectrographic examination, the latter indicating the presence or absence of various minor oxides.

The microscopic examination showed that so many finely divided inclusions of other minerals are contained in the greenalite that its separation for chemical analysis is impossible. Hence its composition was determined indirectly, but by a somewhat more accurate method than any used previously.

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[9] Leith, C. K., *op. cit.* (Monograph **43**), p. 255, 1903.

The Genesis of the Lake Superior Iron Ores: *Econ. Geol.*, vol. **I**, p. 47, 1905.

[10] Moore, E. S., The Iron Formation on Belcher Islands, Hudson Bay, etc.: *Jour. Geol.*, vol. **26**, 435, 1918.

[11] Gruner, J. W., The Origin of Sedimentary Iron Formations; the Biwabik Formation of the Mesabi Range: *Econ. Geol.*, vol. **17**, p. 459, 1922.

Contributions to the Geology of the Mesabi Range: *Bull. Minn. Geol. Surv.*, vol. **19**, p. 63, 1924.

[12] Gill, J. E., Origin of the Gunflint Iron-bearing Formation: *Econ. Geol.*, vol. **22**, pp. 726, 727, 1927.

MICROSCOPIC STUDY

The most characteristic and conspicuous feature of Mesabi greenalite rock under the microscope is the presence of numerous small rounded granules which make up over 70% of the rock volume. Some of these are homogeneous—composed entirely of either green isotropic material, mottled green anisotropic material, or a colourless to pale yellow fibrous mineral aggregate; whereas others consist of various combinations of these. The materials present in minor quantities are iron oxides and quartz. In the specimens examined all the various types of granules seem to have been derived from granules composed originally of pure green isotropic material. Steps in this alteration are illustrated in figures 1 and 2.

The matrix surrounding the granules is composed of quartz and a fibrous mineral. The latter is somewhat lighter in colour than the fibrous aggregates noted above as occurring in altered granules. On close inspection the deeper colour of the fibrous mineral in the granules is seen to be due to brown iron oxides and remnants of unchanged green material. The quartz of the matrix is rather finely crystalline though in places it shows evidences of later recrystallization into larger units. Where the matrix is predominantly quartz the granules are composed mainly of green isotropic and anisotropic material. Where the fibrous mineral predominates in the matrix, the granules are largely altered to the same fibrous mineral. This is illustrated in the following micrometric analyses giving areal percentages:

TABLE 1

Minerals in granules			Minerals in matrix	
Isotropic green material	Anisotropic green material	Fibrous mineral	Fibrous mineral	Quartz
1. 28.4%	21.1%	9.9%	15.7%	24.9%
2. 2.1	27.3	36.6	30.6	3.4
3. 6.0	46.2	12.7	14.7	20.4
4. 0.0	53.1	25.2	19.5	2.2

Analyses 3 and 4 illustrate further that the nature of the matrix bears no relation to the amount of isotropic green material altered to mottled anisotropic green aggregates.

Besides the above minerals or aggregates present in the granules and matrix, there are numerous small veinlets carrying quartz with minor amounts of carbonates and iron oxides. These veinlets cut both the granules and matrix except where the latter is composed of more coarsely crystalline quartz. The latter appears to have been derived from an originally finely-crystalline quartz or chert matrix by later recrystallization.

These various minerals and aggregates making up the bulk of the greenalite rock are:

1. Isotropic Green Material. This consists of an apparently homogenous mineral, transparent to translucent in thin section, and yellow-green to blue-green in colour. It is completely isotropic under crossed nicols, and possesses a refractive index of about 1.675. In some cases such material shows a network of small cracks similar to shrinkage cracks formed in gels, and the absence of any definite orientation to these indicates that true cleavage is wanting. This material would seem to be identical with that to which Leith[13] originally gave the name "greenalite," a name retained in this paper for only the pure isotropic green material.

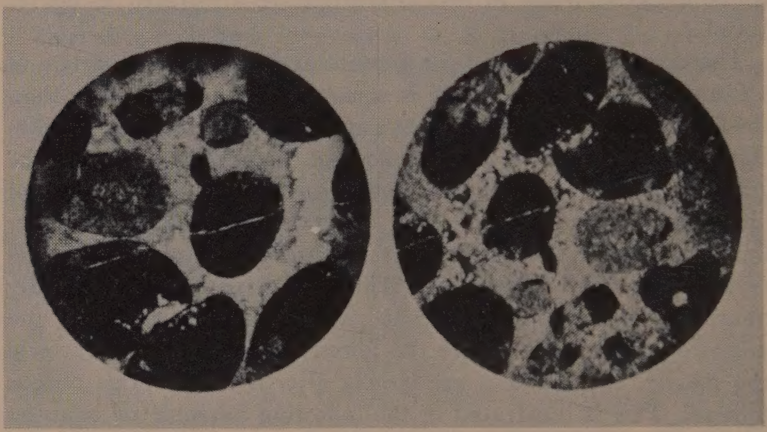

Fig. 1. ×31 (1 nicol) Fig. 2. ×26 (crossed nicols)

Greenalite and metagreenalite granules (black) in various stages of alteration to mineral *X* (grey, mottled by iron oxides and remnants of greenalite). The matrix is quartz and mineral *X*.

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[13] Leith, C. K., *op. cit.* (Monograph **43**), p. 101.

2. Mottled Anisotropic Green Material. Granules composed of this material appear exactly similar to the isotropic greenalite granules except that small, nearly opaque, dark green, indefinitely bounded spots are scattered through parts of them. Under crossed nicols minute pin-points of light are seen which under the highest magnification are resolved into extremely fine needles showing sensibly parallel extinction. Leith[14] describes very similar granules as follows: "Here and there incipient alteration to chert, grünerite, cummingtonite, or actinolite, scarcely discernible in ordinary light, give low polarization colors in minute spots and make the term aggregate polarization applicable." In the present investigation it was not found possible to obtain sufficient data on these fine aggregates to determine definitely the mineral present. Such aggregates have a slightly lower mean index of refraction than the pure isotropic greenalite, while the mean index for the semi-opaque spots is somewhat higher. All gradations between pure isotropic granules and mottled anisotropic granules were observed. The amorphous character of the former as contrasted with the microcrystalline character of the latter, suggests that the greenalite is the primary mineral; the other an alteration product. There is no indication of any marked change in volume, any alteration of matrix, or any subtraction or addition of material taking place during this alteration. In other words, the evidence indicates that the amorphous greenalite, through incipient crystallization, has formed the anisotropic green aggregates. Because of this possible relationship and the general similarity in appearance and structure to greenalite, it is suggested that the mineral (or minerals) making up these mottled green anisotropic aggregates be called "metagreenalite" until further data are obtained.

3. Light-colored Fibrous Mineral (Mineral *X*). This mineral occurs in both granules and matrix. Its distribution in these is characteristic; where granules are largely altered to the fibrous mineral, the surrounding matrix is composed of the same material; and where it is not present in the granules, it is similarly lacking in the immediately surrounding matrix. This association is illustrated in figures 1 and 2, and in table 1. The fibrous mineral definitely replaces greenalite and probably was formed at the expense of both it and the quartz of the matrix. It shows parallel extinction, a small optic angle (normal to the most perfect cleavage), and a fairly

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[14] Leith, C. K., *op. cit.* (Monograph **43**), p. 102.

high birefringence ($N_g - N_p = 1.615 - 1.580 = 0.035$). It has positive elongation and is very slightly pleochroic (Z and Y = pale blue green, X = colorless to pale yellow). In its mode of development, as seen under crossed nicols, it resembles the formation of sericite in feldspathic rocks. It would appear that this mineral is the same as that assumed to be an amphibole by N. H. Winchell[15] and Leith.[16] More recently Richarz[17] has suggested that it be called "crystallized greenalite." However, the analyses made during this investigation indicate a marked difference between the composition of greenalite and that of the fibrous mineral, and indicate that the latter is a new or little known species.* In this paper it will be called mineral X.

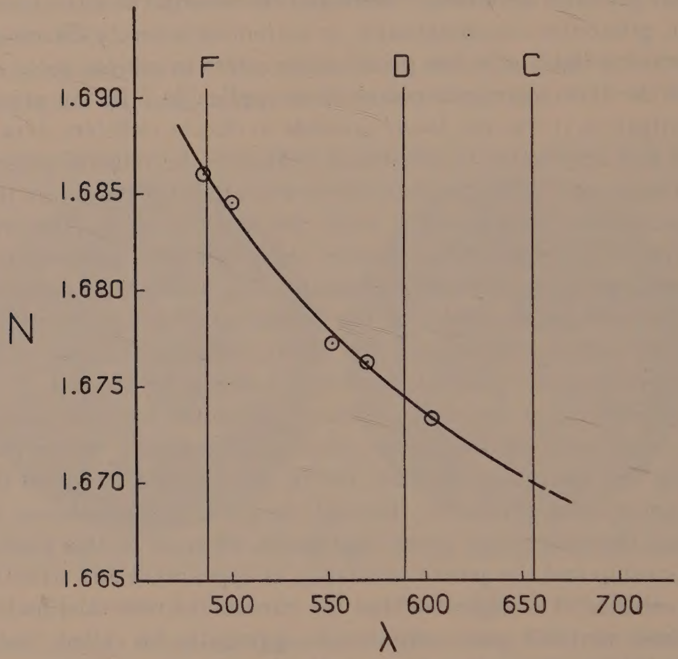

FIG. 3. Dispersion of Greenalite

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[15] Winchell, N. H., *Geology of Minnesota*, vol. V, pp. 927–929, 1900.

[16] Leith, C. K., *op. cit.* (Monograph 43), p. 107.

[17] Richarz, S., Grünerite Rocks of the Lake Superior Region and Their Origin: *Jour. Geol.*, vol. 35, pp. 690–708, 1927.

* Further study of this mineral is being carried on, the results to be published shortly.

4. QUARTZ. This mineral occurs chiefly as a fine mosaic in the matrix surrounding granules of greenalite and metagreenalite. It is usually absent where these granules show much alteration to mineral X. It occurs also, though in very minor amounts, as irregular patches in some of the granules and in veinlets along with carbonates and iron oxides.

5. IRON OXIDES. Small particles of black and brown iron oxides occur scattered through the altered granules and matrix of the greenalite rock. By far the major concentration of these minerals occurs around the outside of the specimens where the latter have obviously undergone weathering.

The above five constituents—greenalite, metagreenalite, mineral X, quartz, and iron oxides—make up more than 99% of the greenalite rock. The relative amounts of these were determined by means of a series of micrometric analyses using a grid eyepiece. These analyses were made on six thin sections cut at various orientations from the same greenalite rock specimen as was used for the chemical analysis. The results are shown in table 2, the average representing closely the mineral composition (by volume) of the greenalite rock.

TABLE 2

	Granules				Matrix	
	Greenalite (isotropic)	Metagreenalite (anisotropic)	Mineral X	Fe oxides	Quartz	Mineral X
1.	5.26	33.49	36.68	4.10	1.62	18.85
2.	19.15	26.70	21.63	1.27	8.65	22.60
3.	13.27	37.57	23.62	0.84	6.55	18.15
4.	17.05	36.05	16.73	0.37	9.00	20.80
5.	7.52	41.55	24.93	1.00	1.65	23.35
6.	14.11	28.82	22.36	1.13	11.00	22.58
Av.	12.72%	34.03%	24.33%	1.45%	6.41%	21.06%

SPECIFIC GRAVITY

Due to the difficulty of separating pure greenalite from its alteration products and other associated minerals, both Spurr[18] and Leith[19] used indirect methods to obtain its specific gravity. The

[18] Spurr, J. E., *op. cit.* p. 238.

[19] Leith C. K., *op. cit.* (Monograph **43**), p. 108.

values arrived at from their calculations were 2.8 and 2.75, respectively.

In this investigation it was found possible to separate a few grains of nearly pure greenalite. These were freed from air bubbles and suspended in Thoulet solutions of different densities. The specific gravities of these grains were found to vary between 2.85 and 3.15, the majority lying close to the mean value of 3.00.

Chemical Composition

On account of the difficulty of separating a sufficient amount of pure greenalite for a chemical analysis, its composition has always been determined indirectly. It has been suggested that it has the composition of glauconite,[20] a distinct species,[21] a garnet,[22] and a chlorite.[23]

In the present study an indirect method was again used but it is believed the result arrived at represents the composition of greenalite almost as closely as if obtained by a direct chemical analysis. The method is as follows:

1. The composition of each mineral in the rock with the exception of greenalite and metagreenalite is obtained.
2. The percentage of each of these minerals in the rock is determined by means of micrometric analyses.
3. From 1 and 2 the total composition of all the minerals present in the rock with the exception of greenalite and metagreenalite is calculated.
4. The values for the different oxides obtained in 3 are subtracted from the total oxide percentages appearing in the chemical analysis of the rock, the remainder giving the sum composition of greenalite and metagreenalite.

The microscopic examination indicated that metagreenalite is crystallized greenalite and both probably have the same composition, hence the value obtained in 4 will represent the composition of pure greenalite.

The weight-percentages of the minerals present in the greenalite rock are obtained from the micrometric analyses (table 2) by multiplying the volume percentage of each mineral by its specific gravity and recalculating to 100%. The results are shown in table 3.

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[20] Spurr, J. E., *op. cit.*, p. 235.

[21] Leith, C. K., *op. cit.* (Monograph **43**), p. 115.

[22] Clarke, F. W., Data of Geochemistry, Bull. **770**, *U. S. Geol. Survey*, p. 584, 1924.

[23] Lindgren, W., *Mineral Deposits*, p. 269, **1933**.

TABLE 3

	Volume per cent	Specific gravity	Weight	Weight per cent
Greenalite	12.72%	3.00	38.2	12.9%
Metagreenalite	34.03	3.00	102.1	34.6
Iron oxides	1.45	5.20	7.5	2.6
Quartz	6.41	2.65	17.0	5.7
Mineral *X*	45.39	2.86	129.8	44.2
	100.00%		294.7	100.0%

TABLE 4

Mineral		Iron oxides	Quartz	Mineral *X*	Totals
% in rock		2.6	5.7	44.2	52.5
SiO_2	% in mineral		100.0	48.7	27.2
	% in mineral x % of mineral		5.7	21.5	
Fe_2O_3	% in mineral	81.6		11.6	7.2
	% in mineral x % of mineral	2.1		5.1	
FeO	% in mineral	18.4		23.1	10.7
	% in mineral x % of mineral	0.5		10.2	
MgO	% in mineral			9.9	4.4
	% in mineral x % of mineral			4.4	
H_2O	% in mineral			6.7	3.0
	% in mineral x % of mineral			3.0	

Of the constituents in table 3, the compositions of the last three were obtainable directly. The iron oxides are assumed to consist of equal amounts of hematite and magnetite. This is in accord with such experimental observations as were made, and even if this assumption were entirely incorrect the results would be only very slightly different due to the small percentage of this material in the rock. The composition of mineral *X* was determined directly by analyzing a small amount of the purified material. This gave the following result (after correcting for impurities and recalculating to 100%):

SiO_2	48.7%
Fe_2O_3	11.6
FeO	23.1
MgO	9.9
H_2O	6.7

From the above data the amounts of the various oxides included in all the minerals excepting greenalite (and metagreenalite) in 100 grams of greenalite rock can be calculated;—as in table 4.

The total composition of the greenalite rock was obtained by means of a chemical analysis checked by a spectrographic examination:

SiO_2	49.43%
("soluble" = 29.90)	
("insoluble" = 19.53)	
TiO_2	none
Al_2O_3	none
Fe_2O_3	8.16
FeO	30.52
MnO	0.17
MgO	4.77
CaO	0.18
Na_2O	none
K_2O	none
P_2O_5	none
H_2O+ (above 110°)	6.24
H_2O- (below 110°)	0.51
CO_2	0.43
Cl, S, SO_3	trace
	100.41
	Specific Gravity = 2.87

The spectrographic examination confirmed the above analysis in every respect. The relatively small amounts of CaO and MnO, and the absence of TiO_2, Al_2O_3, Na_2O, K_2O, P_2O_5, Cr_2O_3, V_2O_3, NiO, CoO, BaO, SrO, B_2O_3, SnO, PbO, and Ag_2O were indicated.

The sum composition of greenalite and metagreenalite is obtained by subtracting the values in the last column of table 4 (representing the amounts of the various oxides in all the minerals except greenalite and metagreenalite) from the total amounts of these oxides appearing in the rock analysis. The results recalculated to 100% represent the chemical composition of greenalite and metagreenalite. This is shown in table 5.

TABLE 5

	% in rock	% in iron oxides quartz and mineral *X*	% in greenalite and metagreenalite	Calculated to 100%
SiO_2	49.4	27.2	22.2	46.8
Fe_2O_3	8.2	7.2	1.0	2.1
FeO	30.5	10.7	19.8	41.7
MnO	0.2		0.2	0.4
MgO	4.8	4.4	0.4	0.9
CaO	0.2		0.2	0.4
H_2O+	6.2	3.0	3.2	6.8
CO_2	0.4		0.4	0.9
Total	99.9*	52.5%	47.4%	100.0%

* Neglecting H_2O-(0.5%), and figures in second decimal place.

From the above table it is seen that greenalite and metagreenalite (with various amounts of other minerals too finely divided to appear in the micrometric analyses) compose 47.4% of the rock. Over 95% of the total composition of all these materials is made up of SiO_2, FeO, and H_2O. The oxides in the remaining 4.7% (Fe_2O_3, MgO, CO_2, CaO, and MnO) probably belong to the finely divided mineral impurities present. Thus, greenalite and metagreenalite appear to be pure hydrous ferrous silicates.

The microscopic examination of thin sections of greenalite rock suggests strongly that the amorphous greenalite altered to metagreenalite by simple crystallization without the addition or subtraction of any material. On this assumption, the total composition of the two minerals should represent the composition of the original pure greenalite. The molecular ratios of the oxides in greenalite on this basis are calculated as follows:

Table 6. Molecular Ratios in Greenalite

		Divided by molecular weight	Molecular ratios
SiO_2	46.8%	0.779	4.02
FeO	41.7	0.582	3.00
H_2O	6.8	0.376	1.94
	95.3%		

The close approximation of these molecular ratios to simple whole numbers lends further support to the assumption stated above and suggests the following formula and composition for greenalite:

$2H_2O.3FeO.4SiO_2$ or $H_2Fe_3(SiO_3)_4.H_2O$

$SiO_2 =$ 48.8
$FeO =$ 43.9
$H_2O =$ 7.3
100.0%

However, despite the weight of evidence justifying the assumption that greenalite and metagreenalite have the same composition, it is possible to state definitely only that greenalite is a hydrous ferrous silicate near $2H_2O.3FeO.4SiO_2$.

III. DISCUSSION OF RESULTS

The foregoing experimental work has established certain new data regarding the composition, properties, association, and alteration of the mineral greenalite. These are discussed below as well as their bearing upon two major problems connected with greenalite: (1) origin of greenalite; and (2) the origin of the Mesabi iron ores.

The results obtained in this investigation support Leith's[24] original contention that greenalite is a definite mineral species distinct from other iron silicates and thus worthy of a mineral name. The accurate determination of refractive index in a number of granules of greenalite has shown that this is a fairly definite quantity. Furthermore, its composition as obtained in this investigation is that of a hydrous ferrous silicate probably possessing a definite formula ($2H_2O.3FeO.4SiO_2$).

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[24] Leith, C. K., *op. cit.*, (Monograph **43**), p. 115, 1903.

On the other hand, the habit of greenalite, its association, and its amorphous character (as shown by isotropism and the absence of all characters indicative of a regular internal arrangement—cleavage, crystal outline, etc.) strongly suggest that it is of colloidal origin. Such minerals do not generally possess a definite composition or formula. Thus, it may be that the whole-number ratio of the oxides in greenalite, as determined in this investigation, is merely fortuitous. However, even if the composition of the mineral be found by later work to vary somewhat, it would still seem to deserve being called a mineral species quite as much as any gel mineral—opal, for example. The crystalline mineral called metagreenalite in this paper must be a definite mineral species. Further study of it involving *x*-ray examination is planned.

ORIGIN OF GREENALITE

The origin of greenalite has been the subject of considerable speculation and experimental study.[25] In the present investigation no further experiments on the synthesis of the mineral were performed but the more accurate determination of the composition of greenalite justifies a brief consideration of theories of its formation. The theories considered here are the two most generally followed:

1. Greenalite is a precipitate deposited from solutions deriving their iron from normal weathering, with or without organic materials assisting in the solution and deposition of iron and in the diagenetic reduction of ferric compounds.
2. Greenalite is a chemical precipitate formed from waters which have received their iron and silica largely by direct contribution from a magma or by the interaction of sea water and hot submarine lavas.

The two properties of greenalite which are most pertinent to any consideration of its origin are habit (texture) and composition.

The granule forms assumed by greenalite are characteristic of the mineral. In the present investigation nothing was observed to indicate that greenalite is a secondary mineral owing its form to replacement of granules of primary material. In all cases the greenalite granules are completely homogeneous except for minor amounts of obvious impurities and alteration products. This strongly suggests that the greenalite represents an original precipitate whose characteristic forms were assumed during the precipitation and were not the results of later diagenetic action. The amorphous character of greenalite and its association with metacolloidal chert indicate that it is a gel mineral. All the greenalite forms observed in the present study could have been produced by purely physical means (surface tension, etc.) if the precipitate were of this gel nature. This is not purely hypothetical since in Leith's[26] synthesis of greenalite such simple granule forms were produced, and even the more complex "tail" structures can be developed by physical (osmotic) processes.[27] Thus, from the textural standpoint, the present investigation supports Leith's thesis that greenalite was precipitated as such in a gel form which physical forces modified during precipitation into the various shapes assumed by the granules.

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[25] Leith, C. K., *op. cit.*, (Monograph 52), pp. 518–529.

With regard to composition, the present study has shown that greenalite is a pure hydrous ferrous silicate. In any theory of origin it is necessary to account not only for the source of the iron (and silica), but also for its occurrence in the ferrous state. The experimental work of Gruner[28] and Moore and Maynard[29] has shown that although large amounts of iron (and silica) may be brought to the sea through normal weathering aided by abundant vegetation, this iron will all be in the ferric state (ferric hydrosol). Consequently, if weathering processes have been the source of the iron in greenalite, reduction must have occurred on a tremendous scale between the time the ferr*ic* hydrosol was brought to the sea by surface waters and the time of its precipitation as a ferr*ous* silicate. The suggestion of Van Hise that the iron was precipitated as a ferric compound, buried with organic matter, reduced, and still later combined with the silica present, is not borne out by the microscopic examination of greenalite rock. Everything—the granule texture, the absence of any indication of the tremendous shrinkage the above process would necessitate, the common occurrence at the present time of ferric hydroxides in bogs with organic matter but showing no evidence of reduction, the low carbon and phosphorus content of the greenalite rock (evidence of little organic material)—seems to indicate that the greenalite was precipitated as such and that diagenetic processes did not assist in its formation. Another possibility is that reduction of the ferric hydrosols took place in the sea before or during the precipitation of greenalite. Such a process might occur through the agency of iron-secreting organisms capable of reducing iron during their life processes. This is, however, entirely hypothetical and is opposed by the general scarcity in the greenalite rock of those elements regarded as indicative of organic agencies—uncombined carbon, and phosphorus. One further possibility has been suggested which has a bearing on this question—that the pre-Cambrian atmosphere was deficient or lacking in oxygen.[30] In this case surface waters could carry and contribute to the sea ferrous salts. From such ferrous solutions, alkaline silicate solutions (likewise of weathering origin) would readily precipitate greenalite. However, the existence of an anerobic atmosphere in late pre-Cambrian times is hypothetical and has been questioned.[31] Furthermore, Gruner[32] has shown the possibility of an extensive land flora at this time, in which case there would be appreciable amounts of oxygen in the atmosphere—sufficient, at least, to prevent the transportation of ferrous iron in surface waters.

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[26] Leith, C. K., *op. cit.*, (Monograph **52**), p. 525.

[27] Hawley, J. E., An Evaluation of the Evidence of Life in the Archean: *Jour. Geol.*, vol. **34**, p. 354, 1926.

[28] Gruner, J. W., The Origin of Sedimentary Iron Formations: *Econ. Geol.*, vol. **17**, pp. 407–460, 1922.

[29] Moore, E. S., and Maynard, J. E., The Solution, Transportation, and Deposition of Iron and Silica: *Econ. Geol.*, vol. **24**, pp. 272–303; 365–402; 506–527; 1929.

On the other hand, recent work by Fenner[33] has indicated a concentration of iron (including ferrous iron) in liquids given off by basic magmas. Furthermore, Leith[34] has shown that alkaline silicate solutions are produced by the reaction of a hot igneous rock with water, and that such solutions combine readily with ferrous salts to form a hydrous ferrous silicate similar in appearance and properties to greenalite, and, like it, possessing a slight excess of silica over the metasilicate ratio.

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[30] Macgregor, A. M., The Problem of the pre-Cambrian Atmosphere: *South African Journal of Science*, vol. **24**, pp. 155–172, 1927.

[31] Quirke, T. T., Discussion on "Origin of Sedimentary Iron Ores": *Econ. Geol.*, vol. **20**, pp. 770–771, 1925.

[32] Gruner, J. W., The Origin of Sedimentary Iron Formations: *Econ. Geol.*, vol. **17**, p. 459, 1922.

[33] Fenner, C. N., The Crystallization of Basalts: *Am. Jour. Sci.* (5), vol. **18**, p. 245, 1929.

[34] Leith, C. K., *op. cit.*, (Monograph **52**), p. 525.

Thus, in summary, most geologists are agreed that the compounds deposited in important amounts in the original Biwabik formation were chert, ferrous silicate, ferrous carbonate, and iron oxides. Of these materials only chert and the ferric oxides could have been deposited from solutions derived from surface weathering. Ferrous carbonate also could have been formed from such solutions provided that an abundance of organic matter was associated with it (cf. the occurrence of siderite in coal seams). On the other hand, without enlisting the aid of organic matter, it is possible for all these materials—chert, ferrous compounds, and iron oxides—to have been precipitated from sea waters which had received direct contributions from an igneous source. Consequently when this consideration is joined with the evidence afforded by the greenalite textures, it strongly favors a direct igneous source for the iron in the greenalite and opposes an origin dependent on weathering processes.

ALTERATION OF GREENALITE

The alteration processes by which iron ores were formed from the original Mesabi rocks have been the subject of recent controversy. The classical theory (developed by Spurr,[35] Van Hise and Leith[36] holds that these ores were formed by the leaching and oxidizing action of cold surface or near-surface waters on the source minerals (chert, greenalite, siderite, and iron oxides). A later view, advanced by Gruner,[37] is that hot waters of igneous origin have been more effective in this alteration.

The present investigation throws little light on this question. Two types of alteration were observed taking place within the greenalite rock:

(1) alteration of greenalite to metagreenalite.
(2) alteration of greenalite to mineral X.

Of these, the first has already been discussed, the conclusion having been reached that the change represents simple crystallization involving possibly a slight segregation or redistribution of certain constituents of the mineral.

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[35] Spurr, J. E., *op. cit.*, p. 253.

[36] Van Hise, C. R., and Leith, C. K., *op. cit.*, pp. 529–546.

[37] Gruner, J. W., Hydrothermal Oxidation and Leaching Experiments; Their Bearing on the Origin of Lake Superior Hematite-Limonite Ores: *Econ. Geol.*, vol. **25**, pp. 697–719; 837–867, 1930.

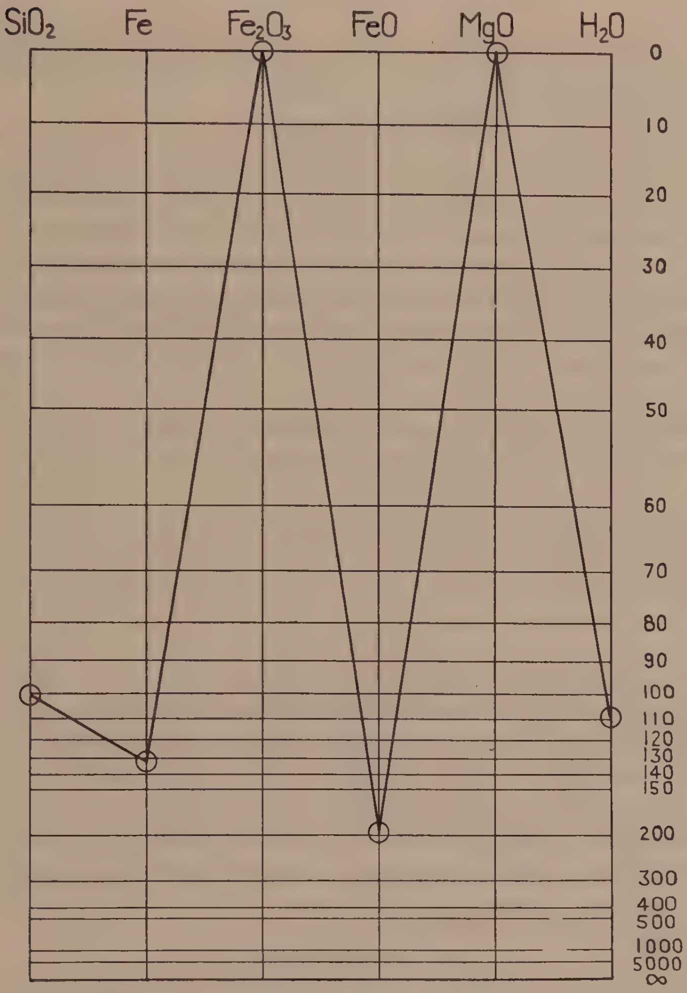

FIG. 4. Alteration of Greenalite to Mineral *X*.

TABLE 7

	Greenalite	Mineral *X*	$\frac{\%\text{ in greenalite}}{\%\text{ in mineral } X} \times 100$
SiO_2	48.8%	48.7%	100.3
Fe	34.2	26.1	131.0
Fe_2O_3	—	11.6	0.0
FeO	43.9	23.1	190.3
MgO	—	9.9	0.0
H_2O	7.3	6.7	109.0

The chemical changes involved in the alteration of greenalite to mineral *X* are shown in table 7 together with their comparison in a straight-line diagram.

In this alteration (relative to total iron) ferrous oxide has been lost, silica and water increased slightly, ferric oxide has been developed, and a relatively large proportion of magnesia introduced. The relations of the minerals as seen in the thin sections suggest that the gain in silica involved in the change from greenalite to mineral *X* has resulted from attack on the quartz matrix. The loss in ferrous iron is accounted for by partial oxidation. The gain in magnesia suggests that the solutions effecting the alteration were high in this constituent. Since only part of the ferrous iron has been oxidized and since considerable magnesia has been introduced, it is probable that this alteration of greenalite was affected by other than surface waters (i.e., either deeper ground waters or hydrothermal solutions). However, the temperature of these waters was probably only moderate, as under even slight heating mineral *X* loses water and forms magnetite by union of the constituent ferrous and ferric oxides.

Thus, both the types of alteration noted within the greenalite rock studied (the crystallization to metagreenalite, and the alteration to mineral *X*) are not due to surface waters. This, however, is not to be interpreted as evidence favoring a hydrothermal origin for the iron ores. In neither of the above types of alteration is any appreciable amount of iron oxides being formed. The only place in the material examined where these oxides are being extensively developed is on the surface where ordinary weathering processes have produced limonite and hematite.

IV. CONCLUSIONS

The conclusions drawn from the results of this investigation may be summarized as follows:

The typical greenalite from the Mesabi iron range is a hydrous ferrous silicate possessing the following properties:

Habit: in rounded granules usually between 0.1 and 1 mm. in diameter, possessing no cleavage or crystal outline.

Color: green (light yellow-green to blue-green) in transmitted light, dark green to black in reflected light.

Specific gravity: 3.0 (varying from 2.85 to 3.15 depending on nature and extent of alteration or crystallization).

Optically isotropic.

Indices of refraction:	N_F	N_D	N_C
	1.686	1.674	1.670
	±0.001	±0.001	±0.002

Dispersion: $F-C=0.016$.

Moderately magnetic.

On heating loses water readily, becomes opaque black in color and strongly magnetic.

The above results rest wholly on the basis of experimental observation. Consequently they are kept separate from the following conclusions which depend on one or two minor assumptions. Thus, it is highly probable:

1. That greenalite is a definite mineral varying only slightly in composition and properties because of its probable colloidal origin.
2. That its composition is most closely represented by the formula $2H_2O.3FeO.4SiO_2$, corresponding to 48.8% SiO_2, 43.9% FeO, and 7.3% H_2O.
3. That its alteration proceeds as follows:
    (A) To iron oxides and hydroxides by the oxidizing and and leaching action of surface waters.
    (B) To an aggregate of minute green crystals associated with small opaque green masses (herein called metagreenalite) by simple crystallization.
    (C) To a light-colored fibrous mineral (herein called mineral *X*) through the agency of magnesium-bearing waters not of surface origin.
    (D) To an intergrowth of magnetite and amphiboles in the vicinity of heated igneous bodies.
4. That its habit and properties show it to be of colloidal origin.
5. That it was deposited as a chemical precipitate from waters which received their iron and silica directly from igneous sources.
6. That it owes its granule form to purely physical processes (surface tension, osmotic pressure) acting on the semi-fluid gel precipitate.
7. That the above conclusions apply to all greenalite throughout the Mesabi range.

THE CRYSTALLOGRAPHY OF HERDERITE FROM TOPSHAM, MAINE

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Abstract

Crystals of herderite, $CaBe(OH,F)PO_4$, from Topsham, Maine, a new locality, exhibit several novelties: prismatic development in the direction of the *c*-axis, twinning on (100), and the new forms $\alpha(\bar{1}04)$, $\beta?(\bar{1}15)$, $\gamma(121)$. Herderite from a new find at Greenwood, Maine, shows the normal columnar development of the clinodome zone and known forms with the addition of $\gamma(121)$. The crystallography of the species is revised and referred to new parameters, $a:b:c=0.6307:1:1.2822$; $\beta=90°6'$, obtained by trebling the *c*-axis of Penfield. The revised form list contains 33 accepted forms (2 new) and 11 uncertain forms (1 new). Three described forms are rejected. For the accepted forms a suitable angle-table is given.

In the summer of 1933 a pocket in the pegmatite of Fisher Quarry, Topsham, Maine, was opened under the active direction of Professor Charles Palache, and an interesting suite of minerals was uncovered. The field relations of this material, which is preserved in the Harvard Mineralogical Museum, were described in a general paper by Palache (1934). The minerals found are more or less typical of the complex acid pegmatites of Maine: cleavelandite, quartz, lepidolite, beryl, topaz, gahnite, tourmaline, garnet, columbite, sericite, apatite, torbernite, cookeite and, last to form, the rare phosphate herderite in considerable abundance.

The herderite occurs in well developed crystals up to nearly 5 cm. long and 3 cm. wide, attached to quartz, cleavelandite, lepidolite, topaz, and sericite. They range from white or greenish-white to colourless; some are stained brown. Among the smaller crystals a considerable number are transparent and fairly brilliant, but all those over half a centimeter long are mottled and translucent. A few crystals are soiled with dried kaolin; the majority, however. are clean and suitable for measurement.

A study of these crystals revealed the fact that herderite presents peculiar goniometric difficulties because of surprising variation in habit and similarity of angles in different zones. It was decided, therefore, to study the crystallography of the species in some detail, supplementing observations on the material from Topsham by measurements on crystals from a new find at Greenwood, Maine, already known through Penfield's work (1894) as a herderite locality. This study suggested a revised statement of the crystallography in which some of the described forms have been rejected and some set aside as uncertain; two new forms have been added to the list of accepted forms and an angle table has been prepared in a suitable form with reference to a new choice of parameters.

Herderite from Ehrenfriedersdorf, Saxony, was recognized as a new species by Haidinger (1828), and described as an othorhombic mineral. E. S. Dana (1884) described crystals from Stoneham, Maine, which he found to be orthorhombic. developed prismatically with the *a*-axis. Penfield (1894) first recognized the monoclinic symmetry of herderite from several localities in Maine, and the twinning, together with nearly rectangular axes, which leads to the orthorhombic appearance of the crystals. He chose an orientation and elements that agreed as closely as possible with the orthorhombic setting of Dana. Thus the clino-axis became the axis of prismatic development with the observed twinning plane as the base. In a short note, Henglein (1909) described a crystal from Epprechtstein, Bavaria, with several new forms, prismatically developed with the *c*-axis and twinned on the orthopinacoid. Dürrfeld (1909 A) discredited Henglein's description, and showed that in the conventional setting, Henglein's supposed new forms were already known on herderite. In subsequent studies, Dürrfeld (1909 B, 1910, 1911) described numerous crystals from Epprechtstein, on which he found several new forms; all the crystals showed the usual prismatic development in the direction of the clinoaxis, with twinning on the base. Ford (1911) added further crystallographic observations on material from Auburn, Maine, retaining Penfield's setting of the mineral.

Four crystals from Topsham were selected for measurement and description. They all proved to be prismatically developed with the vertical axis, two being monoclinic individuals, the other two twins on the orthopinaccid. Since this is the very type of development that was once announced and immediately discredited, it will be necessary to compare the measured angles with those of herderite in the conventional setting and in the position which results from the interchange of the *a*- and *c*-axes.

Two crystals from Greenwood were also measured. They proved to be monoclinic individuals developed equally in the directions of the *a*- and *c*-axes, and terminated in front by positive forms above and negative forms below.

TABLE 1. HERDERITE. TWO-CIRCLE MEASUREMENTS ON SIX CRYSTALS

Forms	Measured						Calculated		Calculated with a- and c-axes interchanged		
	Range		Mean		No. of Faces	No. of Crystals					
	ϕ	ρ	ϕ	ρ			ϕ	ρ	Forms	ϕ	ρ
c 001	90°01′–90°02′	0°17′– 0°27′	90°01′	0°21′	6	5	90°00′	0°06′	a 100	−90°00′	0°06′
b 010	0 00 – 0 04	–	0 02	90 00	8	4	0 00	90 00	b 010	0 00	90 00
a 100	–	–	90 01	90 00	1	1	90 00	90 00	c 001	90 00	90 00
l 120	38 47 –38 55	–	38 51	90 00	4	3	38 24½	90 00	v 011	37 57	90 00
m 110	57 43 –58 10	–	58 00	90 00	20	6	57 45½	90 00	t 012	57 20	90 00
u 013	0 13 – 1 01	23 07 –23 11	0 45	23 09	9	4	0 14	23 08½			
t 012	0 00 – 0 16	32 20 –32 38	0 09	32 32	13	6	0 09½	32 40	m 110	−0 09½	32 14½
v 011	0 04 – 0 29	51 37 –51 58	0 11	51 48	10	4	0 04½	52 03	l 120	−0 04	51 35½
s 021	0 04 – 0 14	68 40 –68 46	0 05	68 44	5	3	0 02½	68 42			
*α $\bar{1}04$	−89 31 –90 50	26 58 –27 07	−90 10	27 03	2	2	−90 00	26 52			
e 102	90 01 –90 02	45 40 –46 06	90 02	45 54	4	4	90 00	45 31	e: $\bar{1}02$	90 00	44 28½
e: $\bar{1}02$	−89 43 –90 01	44 39 –45 36	−89 52	45 07	2	2	−90 00	45 25½			
p 113	57 26 –58 11	38 15 –39 15	57 48	38 47	4	2	57 49½	38 45			
q 112	57 58 –58 33	50 15 –50 18	58 15	50 17	4	2	57 48½	50 16½			
q: $\bar{1}12$	−57 10 –57 40	49 33 –50 30	−57 30	50 01	3	2	−57 43	50 12			
n 111	57 54 –58 12	67 12 –67 42	58 03	67 26	14	6	57 47	67 25½	z: $\bar{1}24$	57 20	66 54½
n: $\bar{1}11$	−57 40 –57 46	66 44 –67 24	−57 44	67 06	3	2	−57 44½	67 74			
r: $\bar{1}23$	−38 04 –40 31	46 41 –47 41	−39 01	47 29	12	5	−38 20	47 27½			
*β $\bar{1}15$	–	–	−61 12	25 11	2	1	−57 39	25 36½			
h $\bar{2}14$	–	–	−72 40	50 30	1	1	−72 28	46 47			
*γ 121	38 31 –40 42	73 25 –74 16	39 41	73 53	13	5	38 26	73 01			

* New form.

The measurements of the six crystals are summarized in table 1, which gives the observed forms, the range of the measured two-circle angles, the resulting averages, and the calculated angles. To these are added the calculated angles of known forms which nearly coincide with different known forms when the *a*- and *c*-axes are interchanged. Although the crystals measured are, like all herderites, only moderately good, it will be seen that the mean measured angles are consistently closer to the calculated angles in proper position than to those resulting from misorientation. Furthermore, most of the forms found are already known in the position in which the crystals were measured, whereas in the alternative position many would give symbols corresponding to unknown forms. The proper orientation and consequently the remarkable development of the Topsham crystals is thus established geometrically. A determination of the optical orientation of one of the measured monoclinic individuals brought independent verification.

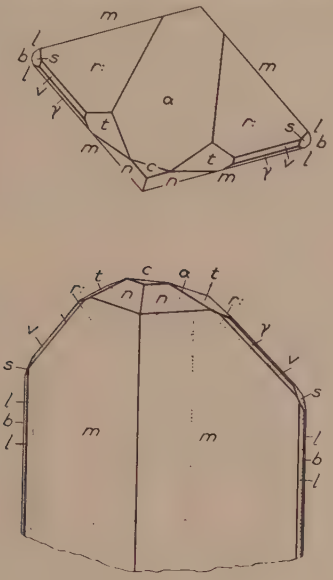

FIG. 1.

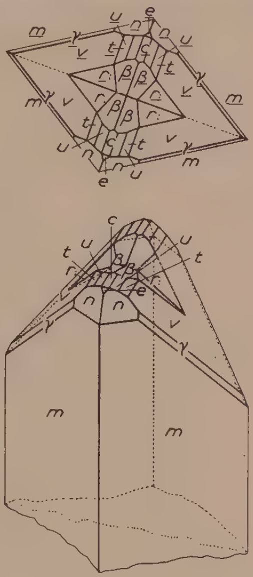

FIG. 2.

FIG. 1. Herderite. Individual crystal from Topsham, Maine, with pronounced monoclinic development. Forms: *c*(001), *b*(010), *l*(120), *m*(110), *t*(012), *v*(011), *s*(021), *α*(1̄04) new, *n*(111), *r*: (1̄23), *γ*(121) new.

FIG. 2. Herderite. Twin on (100) from Topsham, Maine. Forms: *c*(001), *m*(110), *u*(013), *t*(012), *v*(011), *e*(102), *n*(111), *β*?(1̄15) new, *r*:(1̄23), *γ*(121) new.

Figures 1, 2, and 3, illustrate the principal features of the new material. Figure 1 represents a monoclinic individual from Topsham, exhibiting the novel prismatic habit. The crystal is bounded mainly by *m*(110), and the terminal forms $\alpha(\bar{1}04)$ and $r{:}(\bar{1}23)$. The prism *m*(110) is the common prism of herderite. The negative orthodome $\alpha(\bar{1}04)$ is a new form, and appears on this crystal and on another similar one as a large dull but plane face with measured angles agreeing well with the calculated values. The negative pyramid $r{:}(\bar{1}23)$, a common form on herderite, is likewise dull and gives weak reflexions. The edges between the terminal forms and the prisms are truncated by small faces of the known forms: *c*(001), *t*(012), *v*(011), *s*(021), *n*(111), and $\gamma(121)$, which is a new form. The acute edges of the prism *m* are truncated by narrow faces of *b*(010) and *l*(120). The new pyramid $\gamma(121)$ was observed on all the Topsham crystals and also on one of the crystals from Greenwood. On the Topsham crystals it occurred characteristically as two narrow faces in the zone [*m v r*:].

Figure 2 also illustrates a Topsham crystal developed prismatically like the one described above and twinned on the orthopinacoid. The prism zone is bounded by *m*(110) only, while the termination is formed mainly by the faces of the clinodome *v*(011) in nearly parallel position on the two individuals. Indication of twinning is given by a deep re-entrant following the plane of (100) and dividing the termination symmetrically. The re-entrant is formed by badly etched and curved faces of $r{:}(\bar{1}23)$ and $\beta(\bar{1}15)$, a new form the symbol of which is regarded as doubtful since the surface gave very poor reflexions. Smaller faces of *c*(001), *u*(013), *t*(012), *n*(111), and the new form $\gamma(121)$ are also found on the terminations.

Penfield (1894) showed that the twinning of herderite can be referred to either *c*(001) or *a*(100) as the twinning plane, and figured a twin with hypothetical traces of both planes. All of the actual twins with visible re-entrants described by him indicated twinning on *c*(001). Such twinning should give parallelism in the two clinodome zones, whereas twinning on *a* should result in coincidence in the prism zones. Careful observations on the Topsham crystals showed that both the prism zones and the clinodome zones deviate slightly from exact parallelism. It therefore seems best to regard the composition plane (100) as the twin plane; the twinning thus becomes an example of the alternative and hitherto unobserved expression of Penfield's twin law.

Figure 3 shows a typical crystal from the new occurrence at Greenwood. As in most of the published figures of herderite, the form of the crystal is determined mainly by the clinodome zone. The forms observed on two crystals of this type are *c*(001), *a*(100), *b*(010), *l*(120), *m*(110), *u*(103), *t*(012), *e*(102), *e*:($\bar{1}$02), *p*(113), *q*(112), *q*:($\bar{1}$12), *n*(111), *n*:($\bar{1}$11), *r*:($\bar{1}$23), *h*($\bar{2}$14), *γ*(121). The negative forms are all more or less etched and rounded, a common characteristic of herderite and further confirmation of the non-equivalence of the positive and negative forms, even though the angles are nearly alike.

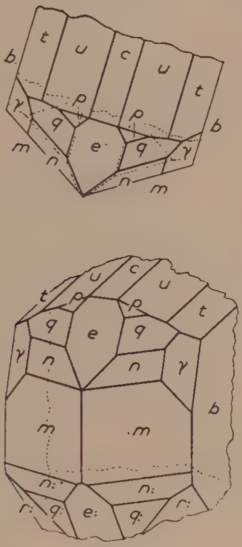

FIG. 3. Herderite. Individual crystal from Greenwood, Maine, with orthorhombic appearance. Forms: *c*(001), *b*(010), *m*(110), *u*(013), *t*(012), *e*(102), *e*:($\bar{1}$02), *p*(113), *q*(112), *q*:($\bar{1}$12), *n*(111), *n*:($\bar{1}$11), *r*:($\bar{1}$23), *γ*(121) new.

The Greenwood crystals gave good angles in close agreement with the angles calculated from Penfield's elements; the angles measured on the Topsham specimens agree less closely. From the best measurements on the latter an axial ratio, which compares with earlier values as follows, was obtained:

a :*b*: *c*	*β*
0.6237:1:0.4255	90°15′ (Yatsevitch, 1935)
0.6246:1:0.4258	..... (Dürrfeld, 1909)
0.6308:1:0.4274	90°06′ (Penfield, 1894)
0.6206:1:0.4236	90° (Dana, 1884)

Since the measurements made in this study are less comprehensive than those of Penfield, the calculated angles are based on Penfield's measurements referred to new parameters as explained below.

In the monoclinic system a setting in which the clinoaxis is the axis of columnar development is ungainly and inconvenient. However, since columnar development may follow either the *a*-axis or the *c*-axis in herderite, nothing will be gained by a rotation of axes. In the adopted setting, therefore, the axial directions of the previous workers are retained, so that the figures present the same aspect as those already published. A consideration of the symbols of the known forms of herderite in relation to the importance of the corresponding forms suggested a new choice of the unit pyramid that results in trebling the *c*-axis of Penfield. Goldschmidt (1897) already simplified the symbols of herderite by taking a *c*-axis equal to three-halves of Penfield's. Our choice of the unit pyramid, namely *n*(111), the only pyramid found at every known herderite locality, results in further simplification as can be seen by comparing the lists of symbols for corresponding forms in the three settings in table 2. Furthermore, the gnomonic projection of the estab-

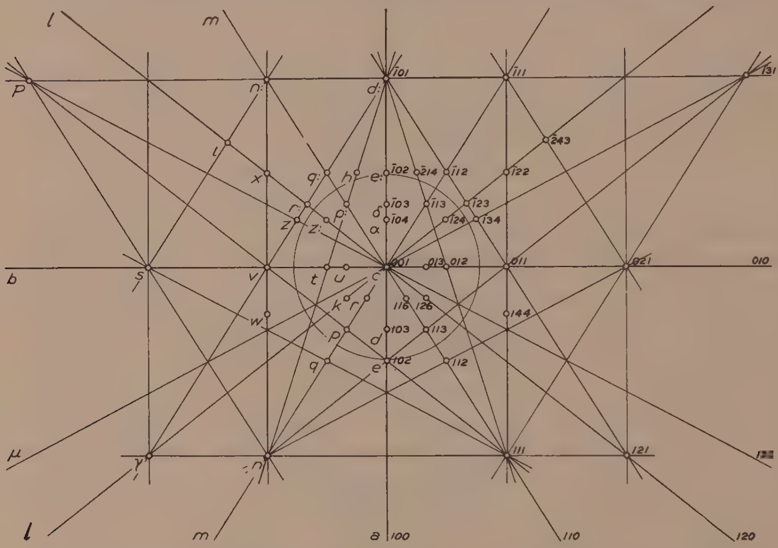

FIG. 4. Herderite. Gnomonic projection of the accepted forms showing the pseudo-orthorhombic character of the species and the importance of the poles of *n*(111), the preferred parametral plane, in the zonal network.

lished forms of herderite (figure 4), shows the importance of $n(111)$ as a zonal node and normal distribution of poles in radial zones.

The elements and symbols in the three settings are related by the following equations:

$$\begin{array}{llll} a:b:c\ \text{(G.M.Y.)} = & a:b:2c\ \text{(Goldschmidt)} = & a:b:3c\ \text{(Penfield)} \\ hkl \quad \text{''} & = hk2l \quad \text{''} & = hk3l \quad \text{''} \end{array}$$

A complete form list of herderite was compiled as a result of an examination of the published work, and is presented in table 2. In the list eleven forms are regarded as uncertain for the reasons given below. Three forms with highly complex symbols are omitted. The following are those considered uncertain:

$f(\bar{2}09)$; described as $f(203)$ by Dürrfeld (1909) with sign uncertain. Later (1910 B) given as $f(\bar{2}03)$. A minute face in poor zonal relation. Possibly the same as the new form from Topsham, $\alpha(\bar{1}04)$.

$E(803)$; $\epsilon(\bar{8}03)$; described without measurements as new forms $E(801)$ and $\epsilon(\bar{8}01)$ by Dürrfeld (1910 A).

$\beta(\bar{1}15)$; described in this paper. "Badly etched and curved."

$g(114)$; g:$(\bar{1}14)$; described as $g(334)$ by Dürrfeld (1909) with sign uncertain. Later (1910 B) given as $g(\bar{3}34)$. In poor zonal relation. Possibly the same as the new and uncertain form from Topsham, $\beta(\bar{1}15)$.

$o(443)$; given as an orthorhombic form $o(441)$ by Haidinger (1828) and never observed again.

$y(133)$; $y(\bar{1}33)$; described as an orthorhombic form $y(131)$ by Dana (1884) from Stoneham, Maine, but not found again. In good zonal relation, but sign unknown.

$G(\bar{3}49)$; described as $g(\bar{3}43)$ by Ford (1911). "Striated and curved"; in poor zonal relation.

$H(135)$; described as $h(395)$ by Dürrfeld (1910 B). "Ein Produkt der Aetzung." In good zonal relation.

The following forms are neglected:

(20.37.0) = l(20.37.0), Dürrfeld (1909). "Uneben und matt."
(881) = p_{24}(24.24.1), Dürrfeld (1909). Vicinal to (110).
(11.22.24) = (11.22.8), Dürrfeld (1909). "Uneben und matt. Wahrscheinlich $x(362)$."

The optical constants of the Topsham material were determined on the measured single crystal illustrated in figure 1, and on grains by the immersion method. The values obtained agree closely with those given by Penfield (1894), and are given below:

$$\left.\begin{array}{l} X\ \text{(obtuse bisectrix)} = 1.591 \\ Y(=b) = 1.611 \\ Z\ \text{(acute bisectrix)} = 1.619 \end{array}\right\} \pm 0.003$$

$2V = 75° \pm 5°; r > v.$

Z:c-axis $= 3\tfrac{1}{2}°$.

TABLE 2. HERDERITE. DISTRIBUTION AND CORRELATION OF FORMS

Symbols Dana (1884) Penfield (1894)	Stoneham[1]	Paris[2]	Hebron[2]	Auburn[3]	Greenwood[4,5]	Topsham[5]	Epprechtstein[6] Ehrenfriedersdorf	Symbols Goldschmidt (1897, 1918)	Letters & Symbols Yatsevitch
001	*c*	*c*	*c*	*c*	*c*	*c*	*c*	001	*c* 001
010	*b*	*b*	—	*b*	*b*	*b*	—	010	*b* 010
100	—	*a*	—	—	*a*	—	*a*	100	*a* 100
130	*μ*	—	—	—	—	—	—	130	*μ* 130
120	*l*	—	—	—	*l*	*l*	*l*	120	*l* 120
110	*m*	*m*	*m*	*m*	*m*	*m*	*m*	110	*m* 110
011	*u*	—	—	—	*u*	*u*	—	023	*u* 013
032	*t*	*t*	—	*t*	*t*	*t*	*t*	011	*t* 012
031	*v*	*v*	—	*v*	—	*v*	*v*	021	*v* 011
061	*s*	*s*	—	—	—	*s*	—	041	*s* 021
$\bar{2}03$	—	—	—	—	—	—	*f*	$\bar{4}09$	*f* $\bar{2}09$?
$\bar{3}04$	—	—	—	—	—	*α*	—	$\bar{1}02$	**α* $\bar{1}04$
101	*d*	—	—	—	—	—	—	203	*d* 103
$\bar{1}01$	—	—	—	—	—	—	*δ*	$\bar{2}03$	*δ* $\bar{1}03$
302	*e*	*e*	—	*e*	*e*	*e*	*e*	101	*e* 102
$\bar{3}02$	*e*:	—	—	—	*e*:	—	—	$\bar{1}01$	*e*: $\bar{1}02$
$\bar{3}01$	—	—	—	*d*:	—	—	—	$\bar{2}01$	*d*: $\bar{1}01$
801	—	—	—	—	—	—	*E*	16.0.3	*E* 803?
$\bar{8}01$	—	—	—	—	—	—	*ε*	$\overline{16}.0.3$	*ε* $\bar{8}03$?
112	—	*r*	—	*r*	—	—	—	113	*r* 116
$\bar{3}35$	—	—	—	—	—	*β*	—	$\bar{2}25$	**β* $\bar{1}15$?
334	—	—	—	—	—	—	*g*	112	*g* 114?
$\bar{3}34$	—	—	—	—	—	—	*g*	$\bar{1}12$	*g*: $\bar{1}14$?
111	*p*	—	—	—	*p*	—	*p*	223	*p* 113
$\bar{1}11$	—	—	—	—	—	—	*p*:	$\bar{2}23$	*p*: $\bar{1}13$
332	*q*	*q*	*q*	*q*	*q*	—	*q*	111	*q* 112
$\bar{3}32$	*q*:	—	—	—	*q*:	—	*q*:	$\bar{1}11$	*q*: $\bar{1}12$
331	*n*	*n*	*n*	*n*	*n*	*n*	*n*	221	*n* 111
$\bar{3}31$	*n*:	*n*:	—	*n*:	*n*:	—	*n*:	$\bar{2}21$	*n*: $\bar{1}11$
441	—	—	—	—	—	—	*o*	883	*o* 443?

TABLE 2—(*Continued*)

Symbols Dana (1884) Penfield (1894)	Stoneham[1]	Paris[2]	Hebron[2]	Auburn[3]	Greenwood[4,5]	Topsham[5]	Epprechtstein[6] Ehrenfriedersdorf	Symbols Goldschmidt (1897, 1918)	Letters & Symbols Yatsevitch
122	—	*k*	—	—	—	—	—	123	*k* 126
392	—	—	—	—	—	—	*h*	265	H 135?
3.12.4	—	*w*	—	—	—	—	—	142	*w* 144
$\bar{3}64$	—	—	—	—	*z*:	—	—	$\bar{1}22$	*z*: $\bar{1}24$
$\bar{3}94$	—	*z*	—	—	—	—	—	$\bar{1}32$	*z* $\bar{1}34$
$\bar{1}21$	—	—	—	*r*:	*r*:	*r*:	*r*:	$\bar{2}43$	*r*: $\bar{1}23$
$\bar{3}43$	—	—	—	*g*	—	—	—	$\bar{6}89$	*G* $\bar{3}49$?
131	*y*	—	—	—	—	—	—	263	*y* 133?
$\bar{1}31$	*y*	—	—	—	—	—	—	$\bar{2}63$	*y*: $\bar{1}33$?
$\bar{6}34$	—	—	—	*h*	*h*	—	—	$\bar{2}12$	*h* $\bar{2}14$
$\bar{3}62$	*x*	—	—	—	—	—	*x*	$\bar{1}21$	*x* $\bar{1}22$
$\bar{2}41$	—	—	—	—	—	—	*i*	$\bar{4}83$	*i* $\bar{2}43$
361	—	—	—	—	γ	γ	—	241	*γ 121
$\bar{3}91$	—	—	—	—	—	—	*p*:	$\bar{2}61$	*P* $\bar{1}31$

* New form. German form letters taken from the literature are consistently replaced by the corresponding English letters followed by a colon.

[1] Dana (1884), Penfield (1894).

[2] Penfield (1894).

[3] Penfield (1894), Ford (1911).

[4] Penfield (1894, Yatsevitch (1935).

[5] Yatsevitch.

[6] Haidinger (1828), Dürrfeld (1909–1910).

In conclusion, an angle table for herderite is presented in a form which combines the requirements of both single-circle and two-circle goniometry. The angles ϕ_2, ρ_2, are two-circle angles referred to the *b*-axis as pole, while the angles A, B, C are *hkl*:(100), *hkl*:(010), *hkl*:(001) respectively. This method of presentation was described in a recent paper by Peacock (1934).

TABLE 3. HERDERITE—$CaBe(OH, F)PO_4$

Monoclinic: $a:b:c=0.6307:1:1.2822;\ \beta=90°06'$.
$p_0:q_0:r_0=2.0330:1.2822:1;\ \mu=89°54'$.
$r_2:p_2:q_2=1.5598:1.5855:1$.
$p_0'=2.0331,\ q_0'=1.2822;\ x_0'=0.0017$.

Forms	ϕ	ρ	ϕ_2	$\rho_2=B$	C	A
c 001	90°00′	0°06′	89°54′	90°00′	0°00′	89°54′
b 010	0 00	90 00	—	0 00	90 00	90 00
a 100	90 00	90 00	0 00	90 00	89 54	0 00
μ 130	27 51½	90 00	0 00	27 51½	89 57	62 08½
l 120	38 24½	90 00	0 00	38 24½	89 56½	51 35½
m 110	57 45½	90 00	0 00	57 45½	89 55	32 14½
u 013	0 14	23 08½	89 54	66 51½	23 02½	89 54½
t 012	0 09½	32 40	89 54	57 20	32 40	89 55
v 011	0 04½	52 03	89 54	37 57	52 03	89 56½
s 021	0 02½	68 42	89 54	21 18	68 42	89 58½
*α $\bar{1}04$	−90 00	26 52	116 52	90 00	26 58	116 52
d 103	90 00	34 11½	55 48½	90 00	34 05½	55 48½
δ $\bar{1}03$	−90 00	34 03½	124 03½	90 00	34 09½	124 03½
e 102	90 00	45 31	44 29	90 00	45 25	44 29
e: $\bar{1}02$	−90 00	45 25½	135 25½	90 00	45 31½	135 25½
d: $\bar{1}01$	−90 00	63 47½	153 47½	90 00	63 53½	153 47½
r 116	57 53½	21 54½	71 11½	78 34	21 49½	71 34½
p 113	57 49½	38 45	55 48½	70 32	38 40	58 00½
p: $\bar{1}13$	−57 41½	38 39	124 03½	70 30	38 44	121 52
q 112	57 48½	50 16½	44 29	65 48½	50 11	49 24
q: $\bar{1}12$	−57 43	50 12	135 25½	65 46½	50 17	130 30½
n 111	57 47	67 25½	26 10½	60 30½	67 20½	38 37½
n: $\bar{1}11$	−57 44½	67 24	153 47½	60 28½	67 29	141 19½
k 126	38 33	28 39½	71 11½	67 58½	28 35½	72 36½
w 144	21 41½	54 04	62 58½	41 12	54 02	72 35½
z: $\bar{1}24$	−38 18½	39 15	116 52	60 14	39 15	113 05½
z $\bar{1}34$	−27 46½	47 23	116 52	49 22½	47 26	110 03½
r: $\bar{1}23$	−38 20	47 27½	124 03½	54 41½	47 31½	117 11½
h $\bar{2}14$	−72 28	46 47	135 25½	77 19	46 52½	134 01
x $\bar{1}22$	−38 21½	58 33	135 25½	48 01	58 32	121 58

TABLE 3—(*Continued*)

Forms	ϕ	ρ	ϕ_2	$\rho_2=B$	C	A
i $\bar{2}43$	−38 22½	65 22	143 32½	44 33	65 25½	124 21
*γ 121	38 26	73 01	26 10½	41 29	72 57	53 31½
P $\bar{1}31$	−27 50½	77 03	153 47½	30 29	77 06	117 04½

* New form.

ACKNOWLEDGMENTS

The author wishes to recognize his indebtedness to Professor Charles Palache, under whose direction this work was done, and in particular to Dr. M. A. Peacock, under whose guidance and with whose help the study was carried out.

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PETROGRAPHY OF THE ROY, HARDING COUNTY, NEW MEXICO, METEORITE[1]

ROBERT E. S. HEINEMAN.[2]

The discovery of the Roy aerolite has been described by H. H. Nininger[3] in a recent article. A fragment of the stone, weighing 192.4 grams, and having a specific gravity of 3.39 was received from Mr. Nininger for the petrographic study. A small portion was broken from this piece and a polished surface examined. This polished surface fragment was then made into a thin-section, which, when completed, was 15 by 20 mm. in size.

The interior of the aerolite is generally chocolate-brown in color due to the presence of a relatively high amount of sesquioxide of iron. A few scattered spots are lighter tinted where the silicate minerals are not as highly stained with the oxidized material. The stone is fairly compact and, while it has a rough fracture, it breaks across both chondrules and matrix. It would be classified as a crystalline chondrite, but only after a microscopic examination as the chondrules cannot be easily distinguished in the hand-specimen.

The polished surface shows scattered, irregularly-shaped grains of a nickel-iron alloy, ranging from microscopic particles up to pieces approximately 2 mm. in diameter. The boundaries of the grains show alteration to and replacement by oxidation products. On etching the nickel-iron fragments with nitol[4] no octahedral Widmanstätten structure was obtained, but, instead, a roughly five- and six-sided, rather coarse granularity was noted. The alloy appeared to be constant in composition and the trias could not be distinguished. A few very fine Neumann lines were observed. In direction they bore no relation to the granularity of the alloy.

Considerable troilite is present in rather thin, irregularly shaped, elongated patches, seemingly a post-silicate fissure filling or replacement. In reflected light the troilite is brass-yellow in color and between crossed-nicols showed marked anisotropism. The matrix shows a number of thread-like, irregularly intersecting, dark veinlets. They are probably composed chiefly of ferric oxide.

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[1] Published with the permission of the Director, Arizona Bureau of Mines.

[2] Mineralogist, Arizona Bureau of Mines, Tucson, Arizona.

[3] Nininger, H. H., The Roy Aerolite: *Popular Astronomy*, **XLIII,** 10, pp. 599–600, 1934.

[4] 5% solution of nitric acid in alcohol.

The thin section proved the aerolite to be a crystalline chondrite. The chondrules are very numerous and varied in character. They are scattered throughout a crystalline ground-mass which is composed largely of fragmental silicate grains, although a few euhedral crystals of chrysolite and one of enstatite were seen. The ground-mass is heavily stained brown with ferric oxide between the grain boundaries and along fractures and cleavages. The ground-mass silicate is chiefly chrysolite.

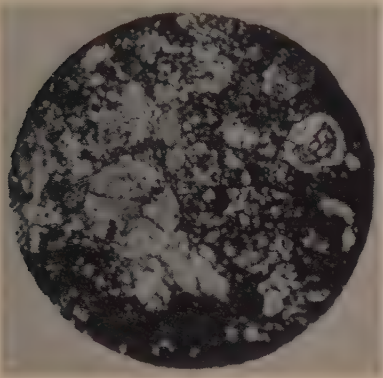

Fig. 1. General view. Note large enstatite chondrule. ×7.

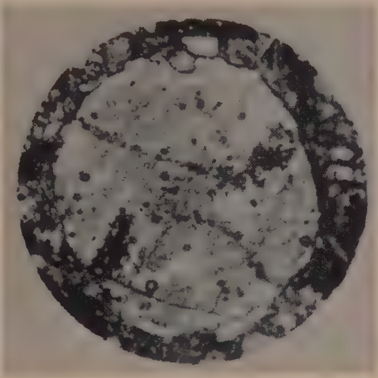

Fig. 2. Enstatite chondrule. ×20.

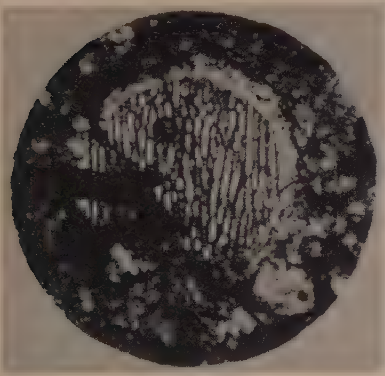

Fig. 3. Barred chrysolite chondrule. ×37.

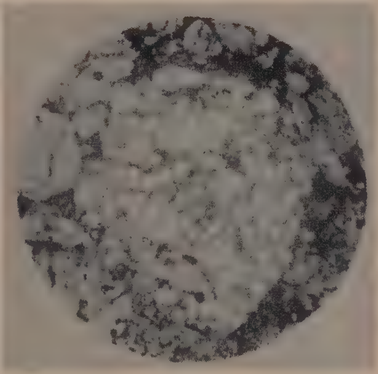

Fig. 4. Porphyritic chondrule. ×23

The chondrules vary in size up to 2 mm. The largest one observed is a spherical enstatite chondrule and is shown in figure 2. There are no particularly unusual features in the stone, but it is of interest because of the variety of types of chondrules present. There are are the barred chrysolite type, the radiating enstatite (bronzite) type, and the porphyritic type. Many of the chondrules are almost perfect spheres, but some are ellipsoidal in shape and many are fragmental. It is difficult to give a clear description of the structure of a stony meteorite and a better idea may be obtained by referring to the photomicrographs of the thin-section. Figure 1 is a general view at relatively low magnification. The enstatite chondrule mentioned previously may be seen in figure 2. Figure 3 shows a

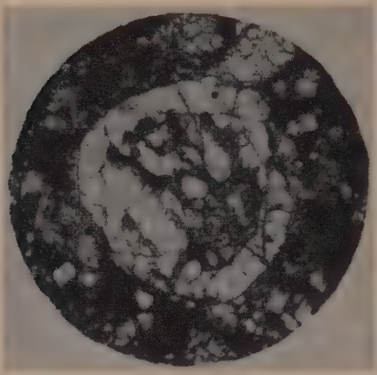

Fig. 5. Bordered, twinned chrysolite chondrule. ×27.

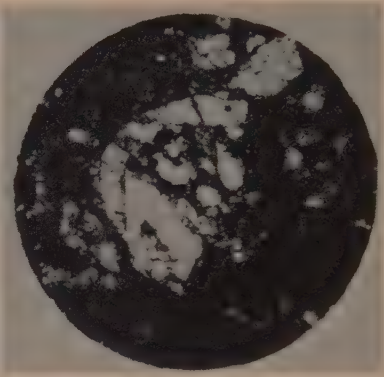

Fig. 6. Same chondrule as Fig. 5, showing twinning. Crossed nicols. ×27.

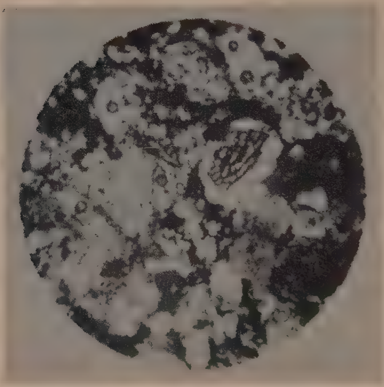

Fig. 7. Group of chrysolite chondrules with inclusions and several fragmental enstatite chondrules. ×20.

barred chrysolite chondrule, and a porphyritic chondrule enlarged is shown in figure 4. The particles composing this chondrule are chiefly chrysolite. A bordered twinned chrysolite chondrule is shown in figures 5 and 6. In figure 7, a chrysolite chondrule with inclusions and several fragmental enstatite chondrules may be seen. This same figure shows a number of small incipient chondrules within large chondrules and crystal grains.

A chemical analysis of the stone was made by F. G. Hawley[5] and is as follows:

Metallic portion:	0.04 grams.	
Non-metallic portion:	50.00 grams.	
Silicate analysis:		
SiO_2		36.95%
Al_2O_3		2.92
Fe_2O_3		13.29
Cr_2O_3		0.43
FeO		12.57
MnO		0.16
NiO		1.27
CoO		0.14
CuO		0.10
MgO		23.10
CaO		2.50
Na_2O		0.26
K_2O		0.06
TiO_2		0.12
P_2O_5		0.31
FeS		3.58
SO_3		0.69
Loss on ignition		1.88
TOTAL		100.33%

Using this analysis as a base, the mineralogical composition of the silicate portion of the aerolite was calculated by the standard method of norm calculation as applied to stony meteorites by Farrington.[6] This method was, however, changed a little as merrillite ($3\,CaO.Na_2O.P_2O_5$) was calculated instead of apatite, and the orthoclase, albite, and anorthite molecules were combined after calculating to form maskelynite. No crystalline plagioclase could be seen in the slide and neither could any apatite. As the nickel, cobalt and copper were reported as "ous" oxides they had to be combined with FeO and MnO in the calculations, but the amounts are so small as to be negative in influencing the silicate molecule ratios. The results of the calculations follow:

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[5] Chief Chemist, International Smelting Company, Miami, Arizona.

[6] Farrington, O. C., Analyses of Stone Meteorites Compiled and Classified: *Field Col. Mus. Pub.* **151,** *Geol. Ser.*, vol. 3, pp. 197–208, 1911.

Maskelynite	8.56%
Diopside	2.91
Enstatite	31.20
Chrysolite	36.19
Chromite	0.67
Ilmenite	0.15
Merrillite	0.74
Troilite	3.58
Oxidation products, $Fe_2O_3+SO_3+$Loss on ignition	15.86
TOTAL	99.86%

The ratio FeO:MgO in the silicates is approximately 1:3 which would make the enstatite the variety bronzite. The relatively large amount of oxidized material, of course, changes the percentage composition of the stone as it now is considerably from its composition at the time of fall, before the oxidation took place. The 13.29 per cent of ferric oxide would be derived chiefly from the oxidation of metallic iron. The SO_3 probably came from the oxidation of troilite.

U-GALENA AND URANINITE IN BEDFORD, NEW YORK, CYRTOLITE

Paul F. Kerr, *Columbia University, New York City.*

Introduction

A short time ago a polished surface of cyrtolite was prepared from a slab cut from the side of one of the specimens of cyrtolite used by Luquer (1) in his original description of cyrtolite from Bedford, New York. Observation of the polished surface with a hand lens revealed the presence of numerous metallic specks. Examination with the reflecting microscope indicated that the metallic specks were galena. Ordinarily the discovery of small amounts of galena even in material from a pegmatite in the vicinity of Bedford would call for no more than passing comment. Bedford cyrtolite, however, has been investigated so intensively in recent years in connection with age determinations based upon the lead-uranium ratio and the atomic weight of lead, that it is felt the occurrence of galena in cyrtolite from this locality should receive special attention. A number of specimens have been studied therefore and a short account has been prepared for the purpose of placing on record a description of what appears to be an unusual occurrence of galena. It is possible from chemical data already published to infer the presence of the uranium isotopes of lead as part of the galena. Such an occurrence of what might be called U-galena should be of interest. The microscopic studies connected with the determination of the galena have disclosed certain data concerning the occurrence of the uranium in the cyrtolite also worthy of comment. Further studies of the Bedford cyrtolite and cyrtolite from other localities are in progress and will be published later. Little attention will be paid therefore in the present discussion to the nature of cyrtolite.

Determination and Distribution of the Galena

A photomicrograph of galena as it occurs in the Bedford cyrtolite is shown in figure 1. In the area photographed the galena fills a small cavity bordered by cyrtolite, unreplaced zircon and muscovite. The galena is restricted in its occurrence to cavities or fractures in the cyrtolite, and is evidently one of the later minerals to form in the history of the specimen. The only later mineral in the specimen examined is autunite which is apparently entirely secondary and restricted to one or two later fractures. Uraconite was present in some of the material described by Luquer but was not observed in thin sections or fragments of specimens used for the present study.

The galena shows the criteria by which the mineral is ordinarily recognized on polished surfaces. It exhibits triangular cleavage pits, scratches due to abrasive powder cutting a soft mineral in polishing, low relief, and a characteristic blue gray color in reflected light. It contains occasional needle-like crystals of an unidentified mineral visible only under the microscope.

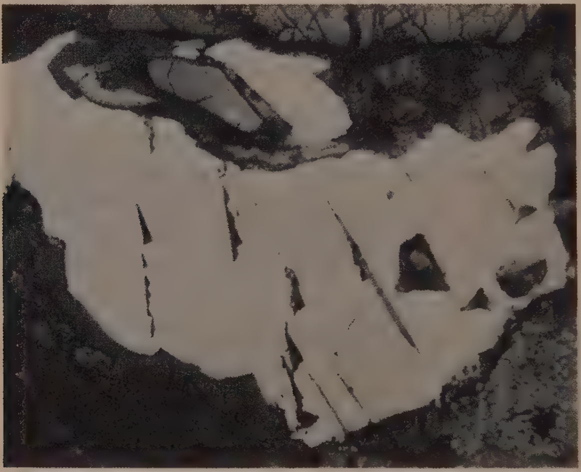

FIG. 1. U-galena in Bedford cyrtolite. The mineral exhibits the characteristic triangular pits of common galena on a polished surface. (Photomicrograph ×150.)

Analysis of Bedford cyrtolite by Mr. Earl Emendorfer of the Department of Geology and Mineralogy, Columbia University, shows the presence of lead and sulphur as follows:

$$Pb = 0.33\%$$
$$S = 0.05\%$$

Although the amounts determined are small the original sample was sufficiently large to justify confidence in the accuracy of the determinations as given.

It is interesting to observe that the Pb:S ratio based upon the above analysis is approximately 1:1. It is probable, therefore, that all of the lead in the Bedford cyrtolite is combined with the sulphur in the form of galena.

Examination of the published accounts of previous investigations of the cyrtolite fails to reveal any mention of sulphur determinations. This is not unusual, however, since the principal analytical ends desired in age determinations of the cyrtolite appear to be: (1) the amount of uranium present, (2) the amount of lead present, (3) the atomic weight of the lead, and (4) the assurance of the absence of thorium. The sulphur is evidently present in the form of a sulphide since only the faintest trace of sulphate may be detected chemically.

The amount of lead in the Bedford mineral was determined by Muench (2) who gave as the average of seven determinations 0.374%. Differences between two different samples and the conditions of analysis by different analysts could easily account for the difference between $Pb=0.33\%$ determined by Emendorfer and $Pb=0.374\%$ determined by Muench. In view of the generally mixed nature of the cyrtolite from Bedford as revealed under the microscope it is doubtful whether two different samples could be found which would yield exactly the same amount of lead.

Radioactive Constituents of Cyrtolite

Cyrtolite has been a material frequently used by mineral collectors for taking radiograms (3). Generally a rough specimen is placed near a photographic plate and allowed to remain for several weeks until the plate is properly exposed. It is possible, however, by using a polished surface to bring out greater detail in a radiogram and also to lessen the time of exposure. Such radiograms usually show sufficient detail to warrant enlargement. The radiogram shown in figure 2 was taken in this way and enlarged three times.

Radiograms of Bedford cyrtolite exhibit a surprising lack of uniformity in the distribution of the strongly radioactive areas as indicated by the white spots and lines on the radiogram in figure 2. The bright white areas and lines in the radiogram are due both to uraninite streaks or grains and veinlets containing autunite. Two long narrow streaks extending along fractures (NW–SE as the picture stands) are due to autunite. A small area in the lower left-hand corner is also due to this mineral. The strong radioactivity of the remainder of the specimen as indicated by numerous

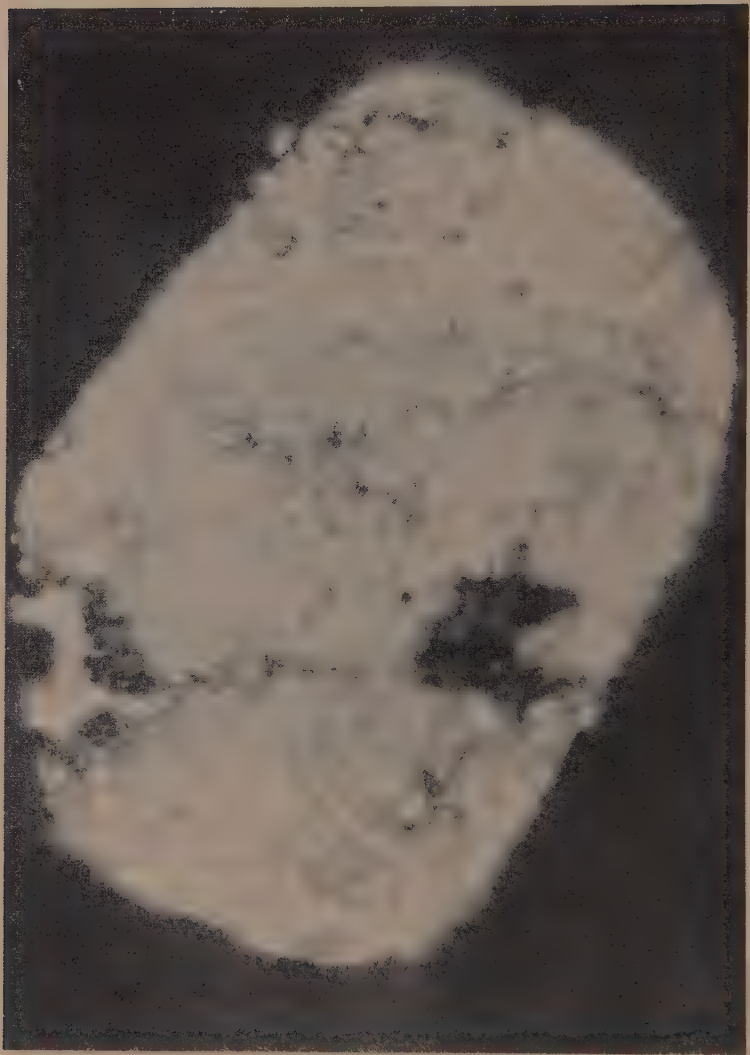

FIG. 2. A radiogram of Bedford cyrtolite. The white areas represent the centers of greatest radioactivity. In order to prepare this exposure a polished surface of cyrtolite was placed directly over a photographic plate and allowed to remain four days in a light tight box. The white spots and short streaks are due to the radioactivity of uraninite. (Enlarged three times.)

short streaks and many bright spots is due to uraninite. The dark and shaded areas in the radiogram intermediate between the bright areas of uraninite represent exposures due either to cyrtolite or to cyrtolite containing finely disseminated grains of uraninite. The effect of cyrtolite on a photographic negative is slight when compared with that of uraninite.

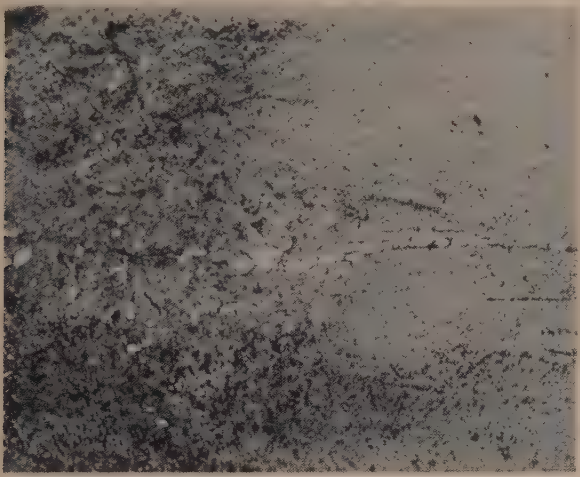

Fig. 3. A veinlet and scattered grains of uraninite. The photomicrograph represents the appearance of a veinlet responsible for one of the streaks in the radiogram. Most of the spots and streaks in the radiogram are due to uraninite of this type. It is not unusual for a veinlet to produce a streak on the radiogram twenty times as broad as the original veinlet. It should be pointed out therefore that the radiogram Fig. 2 gives an exaggerated idea of the actual radioactive area. (Photomicrograph ×150.)

A photomicrograph of uraninite as it occurs in veinlets and disseminated grains scattered through the Bedford cyrtolite appears in figure 3. The veinlets are uniformly small measuring about 0.01 mm. in thickness and are for the most part not more than a centimeter in length. Under the microscope sections of crystals showing cubic outline may be observed in places. *X*-ray diffraction patterns of the cyrtolite have been taken which show extraneous lines agreeing with lines in standard patterns of uraninite. The relief and color of the mineral on polished surfaces as examined under the microscope also agree with uraninite. The veinlets illustrating the appearance of uraninite under the microscope are the same veinlets responsible for the intense radioactivity in the radiogram although exposure due to radioactivity is somewhat diffused. It should be pointed out that Muench in ascertaining the lead-uranium ratio for the Bedford cyrtolite determined the uranium content to be $U=7.29\%$. At the same time he found the mineral to be free from thorium. It seems clear, therefore, that uranium is one of the constitutents of the cyrtolite mixture. Whether uranium is present in the cyrtolite itself or occurs as an impurity is not evident from chemical data. Microscopic and *x*-ray data, however, point to at least a large portion of the uranium being present as finely divided uraninite scattered through the cyrtolite.

On account of the uneven distribution of the uraninite it is doubtful whether two different specimens of cyrtolite would yield the same uranium content. This might affect age determinations as they apply to this mineral but the extent of such influence if effective at all is a problem beyond the scope of this paper.*

U-GALENA

In 1931 when Muench published his interesting account of the Bedford cyrtolite he furnished several determinations of the lead and uranium content of the mineral. On the basis of these determinations and following the usual methods (4) used for the purpose of ascertaining the age from the lead-uranium ratio he computed the age of the cyrtolite, giving an age of 373 million years. More recently Baxter and Alter (5) determined the atomic weight of the lead in Bedford cyrtolite finding the figure 205.924. It was Baxter and Alter's conclusion that the lead was essentially uranium lead, that is lead derived substantially from the disintegration of uranium. The atomic weight is slightly lower than it should be but in any event it is considerably below the atomic weight 207.21 determined by Baxter and Alter (6) for the common lead from Coeur d'Alene, Idaho.

In view of the above chemical data it seems reasonable to conclude that the atomic weight of the lead in the crytolite is not that of common lead. Since the cyrtolite has been considered by both Muench and Baxter and Alter to be thorium free it would not be likely to be of thorium origin. On the other hand the low atomic weight and the presence of uranium indicate a preponderance at least of uranium lead.

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* See Report of the committee on the Measurement of Geologic Time, *Nat. Res. Council*, **1934**, pp. 26 and 46, for comment on the difficulty experienced by Hecht in checking previous cyrtolite age determinations by Muench.

It was indicated above that all of the lead in the cyrtolite was probably combined with sulphur in the form of galena. Since the lead has been shown chemically to be uranium lead it must naturally follow that the galena is made up of isotopic lead in combination with sulphur. The galena in the cyrtolite from Bedford, therefore, is not ordinary galena. It seems appropriate therefore to distinguish it as U-galena since judging from published analyses it must be made up essentially of isotopes of lead derived from uranium.

Uranium lead from uraninite, Wilberforce, Ontario, having the atomic weight (7) 206.195 has been investigated by Aston (8) with the mass-spectrograph. This lead yielded a mean mass number of 206.199 and was made up of isotopes $Pb^{206} = 85.9\%$; $Pb^{207} = 8.3\%$; $Pb^{208} = 5.8\%$. Other samples of uranium lead from Katanga, Africa, Great Bear Lake, Canada, and Morogoro, Africa, also investigated by Aston yielded similarly preponderant amounts of Pb^{206}. Thorium lead on the other hand from Norwegian thorite with an atomic weight of 207.90 determined by Fajans (9) yielded a mean mass number 207.895 and contained the isotopes $Pb^{206} = 4.6\%$; $Pb^{207} = 1.3\%$; and $Pb^{208} = 94.1\%$.

In view of Aston's work it would be expected that the lead in the Bedford galena in common with other uranium lead should contain a preponderant amount of Pb^{206}. Investigation with the mass-spectrograph, however, would be needed to determine the relative abundance of the different isotopes and also to explain the slightly lower atomic weight (205.924) reported by Baxter than reported for other uranium lead samples. On the other hand the fact that the atomic weight is low rather than high strengthens the evidence in favor of the uranium origin.

Unfortunately only small amounts of the U-galena are available for study and it is apparently indistinguishable on a polished surface from ordinary galena. It is likely that this galena may be discovered elsewhere in quantities which will allow study of its physical properties. Galena mentioned by Ellsworth as occurring at at Hybla, Ont., Canada was suggested as possibly being galena of this type (10). According to Alter (11) however, ordinary lead is indicated by a study of Hybla cyrtolite.

It is generally recognized that galena is a common associate of uraninite and occasionally other radioactive minerals. In the usual case, however, the galena has been introduced from an outside source, and the connection with atomic disintegration is difficult to establish.

Evidence concerning the origin of the sulphur was not observed, but the presence of pyrite and pyrrhotite in the adjacent pegmatite at Bedford suggests that solutions carrying sulphur must have been prevalent. Precipitation of galena by reaction of such solutions with radiogenic lead would appear to be a normal result. It is inferred that lead was not introduced in the same way, from the absence of galena elsewhere in the pegmatite and the chemical data on record regarding lead in cyrtolite.

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(3) Manchester, J. G., The minerals of New York City and its environs: *Bull. of N. Y. Mineralogical Club*, vol. **3**, No. 1., 1931.

(4) Knopf, Schuchert, Kovarik, Holmes and Brown, The age of the earth: *Natl. Research Council*, Bull. **80**, 1931.

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(7) Baxter, G. P., and Bliss, A. D., *Jour. Am. Chem. Soc.*, vol. **52**, p. 4851, 1930.

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(9) Honigschmid, O., *Zeit. Electrochem.*, vol. **25**, pp. 91–96, 1919.

(10) Ellsworth, H. V., Rare-element Minerals of Canada: *Canada Dept. of Mines, Geol. Surv., Econ. Geol. Ser.*, No. **11**, p. 204, 1932.

(11) Report of Committee on Measurement of Geologic Time, *Natl. Res. Council*, p. 20, **1934**.

(12) Baxter, G. P., and Alter, C. M., atomic weights of several radiogenic leads, *Jour. Am. Chem. Soc.*, Vol. **55**, pp. 467–469, 1935. (Published while the present paper was in press.)

MICROSCOPIC INVESTIGATION OF FRIEDENSVILLE, PENNSYLVANIA, ZINC ORE

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INTRODUCTION

The zinc mines at Friedensville, Pennsylvania, are situated south of Bethlehem in Saucon Valley, which is developed on a down-faulted block of limestone lying between ridges of pre-Cambrian gneiss to the northwest and southeast. The valley is irregular in outline but is approximately ten miles long and three and one-half miles wide. It is bounded on the northwestern side almost entirely by faults and the southeastern boundary is in part marked by fault lines. In addition, faults cut the limestone of the valley proper both longitudinally and crosswise. The ore is concentrated along these crushed zones.

ACKNOWLEDGMENTS

This paper deals primarily with the microscopical features of the ores, and the writer is indebted to Dr. Benj. L. Miller, whose papers[1] and helpful discussion have contributed much of the information regarding structural relationships and general features of the deposit.

Dr. H. V. Anderson and Mr. E. B. Frazee kindly collaborated and furnished the writer with the results of an *x*-ray examination of certain specimens. Dr. Warren Ewing also assisted the writer by helpful discussion in the application of the laws of physical chemistry.

During the preparation of this paper, the writer learned that Robert D. Butler was examining a variety of sphalerite and associated pyrite found at Friedensville. Mr. Butler sent the writer an abstract of his paper, "Mylonitic Sphalerite from Friedensville, Pa.," which has aided in the understanding of the fractured ore.

PREVIOUS WORKERS—ORIGIN OF ORE

Previous workers concerned primarily with the mineralogy or the origin of the ore include F. A. Genth,[2] H. S. Drinker,[3] J. P. Lesley,[4] F. C. Clerc,[5] and J. F. Kemp.[6] The most comprehensive discussion of the area is given by Benj. L. Miller, who lists a complete bibliography[7] of the Friedensville mines and also summarizes the views of other workers regarding the origin of the ore in the following manner:

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[1] Miller, B. L., Topographic and Geologic Atlas of Pennsylvania: No. **206,** Allentown Quadrangle, *Penna. Geological Survey,* 1925.

Miller, B. L., Lead and Zinc Ores of Pennsylvania: *Topographic and Geologic Survey,* Bulletin **M5,** 1924.

> Drinker supposes, "that the zinc was originally disseminated through the dolomite in the form of carbonate or sulphide." Later the small particles were dissolved by water that contained carbonic acid, converted into zinc sulphate by coming in contact with sulphuric acid that was formed by the decomposition of pyrite, and later precipitated in their present location as zinc sulphide through the action of the organic matter contained in the limestone.
>
> Lesley held somewhat similar views and said that, "it is probable that they (lead and zinc minerals) were deposited with the limestone in far greater abundance in ancient ages and were originally brought into the Appalachian sea as soluble salts, together with the lime and magnesia waters of the primeval rivers," and that, "the dissolution of the lime rocks has produced concentrated masses of zinc ore."
>
> Clerc suggested a deep-seated origin in his published statement that "they belong to a class of deposits which seem to warrant a belief in their continuance to a considerable depth."
>
> Kemp states that "the veins were evidently filled by circulation from below that brought the zinc ore to its present resting place in the shattered and broken belt."

Miller regards the ore as having resulted from the following sequence of events:

> a. "During . . . Cambrian and Ordovician time zinc minerals . . . (were) precipitated in minute disseminated particles in the limestone as sulphides and carbonates."
>
> b. "The waters that concentrated the sphalerite and pyrite were doubtless mainly of meteoric origin, . . ."

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[2] Genth, F. A., Contributions to Mineralogy—Lanthanite: *Am. Jour. Sci.*, 2nd Ser., vol. **XXIII,** pp. 425–426, 1857.

Genth, F. A., Preliminary report on the mineralogy of Pennsylvania: *Pennsylvania Second Geol. Survey*, Rept. **B,** pp. 15, 18–20, 57, 69, 106, 107, 120–122, 149, 161–163, 165, 166, Harrisburg, 1875.

[3] Drinker, H. S., The mines and works of The Lehigh Zinc Company (abstract): *Trans. Am. Inst. Min. Eng.*, vol. **I,** pp. 67–75, 1871.

[4] Lesley, J. P., The Saucon zinc mines in Lehigh County: *Pennsylvania Second Geol. Survey*, Summary Final Report, vol. **I,** pp. 436–443, 1892.

[5] Clerc, F. C., The mining and metallurgy of zinc in the United States,—Pennsylvania: *U. S. Geol. Survey*, Mineral Resources, 1882, pp. 361–365, **1883,** *Eng. & Min. Jour.*, vol. **XXXVI,** pp. 148–149, 1883; *Pennsylvania Second Geol. Survey*, Summary Final Report, vol. **I,** pp. 439–443, Harrisburg, 1892.

[6] Kemp, J. F., Ore deposits of the United States and Canada, second edition, pp. 250–251, **1906.**

[7] Miller, B. L., *loc. cit.*

c. ". . . ascending waters must have brought the sphalerite and pyrite to their present position unless the ground-water level formerly lay at much greater depths than now."

He thus concludes that the ore is due to circulating meteoric water which on ascending deposited zinc sulphide that had been picked up by the solutions in their descent through the limestones.

Magmatic solutions have been suggested as the source of the ore minerals and the presence of Triassic diabase outcropping a few miles south of the ore district must not be disregarded in a consideration of the source of the solutions.

The writer has not found additional facts pertinent to the origin of the solutions which deposited the zinc ore and therefore must regard the deposit to be the result of ascending solutions of unknown origin.

The primary ore is found as disseminated particles and as replacement masses in the limestone, as fissure and cavity fillings and as the cementing material of brecciated areas. Secondary minerals occur as fillings and encrustations along steeply inclined bedding planes, in transverse joints, in solution cavities and as replacements of the limestone.

Microscopic Features

Primary Minerals. The primary sulphides occurring chiefly below the water table, though sometimes above, are sphalerite and pyrite. Greenockite is found in the oxidized ore and it is thought, therefore, that cadmium, probably as a sulphide, is present in the sphalerite.

Sphalerite appears in two distinct types. One, the more common black-jack variety, is coarse-grained and massive with the broken surfaces showing cleavage faces with random orientation. The other type is chert- or flint-like in appearance, ranging from gray-brown to black in color, is dense, massive, and breaks with a conchoidal fracture.

In thin-section the coarser-grained variety is dark brown in color and shows a complete network of fractures traversing the mineral. Between crossed nicols it is noted that the mineral has a clouded appearance not only adjacent to the fracture planes but also for a distance inward equal to several times the width of the apparent fracture zone. Also when the clearer, less prominently fractured parts of the sphalerite are examined, it is found that their diaphaneity is conditioned by countless smaller breaks which appear to be mainly cleavage planes and by numerous granule or rod-like inclusions having diameters of only a few microns. Some of these may be cadmium, probably in the form of the sulphide, but they have not been proven to be such. *X*-ray studies in progress at the present time may give more definite information on this point.

Inasmuch as the clearer, more yellowish sphalerite found in the oxidized ore shows numerous cleavage cracks but is lacking in inclusions and in the network of fractures with crushed borders, it is suggested that the black-jack variety found in the primary ore may be less diaphanous and of a darker color due to these features as well as its probable higher iron content.

The finer-grained sphalerite is described by R. D. Butler[8] as having been formed by crushing; the result being a mylonitic sphalerite. This description is based on observations on polished surfaces. A description of this material in thin-section is given here.

In plane polarized light this yellow brown to dark brown sphalerite is seen to be a granular mass wherein the individual grains are more or less indefinable. This is due to the presence of fractures even in what are apparently the more distinct grains, and also to the overlapping of grains. In a thin-section of the material whose grain size is of the order of several microns in diameter, a few grain-thicknesses are necessary to build up the thin-section which is close to thirty microns thick.

Between crossed nicols two types of material are evident. Brownish material appears in a network of anastamosing wavy bands whereas blacker material lies as elongated areas within the network. The former is interpreted to be the more intensely broken material which is similar in appearance to the crushed areas bordering the fractures in the coarser grained sphalerite. The latter are thought to be "augens" of sphalerite which escaped the minute fracturing of the neighboring material. If this is a correct interpretation, it might be preferable to speak of these specimens of sphalerite as being mylonitized and possessing flaser structure, to indicate the incomplete crushing.

Pyrite is abundantly distributed through the primary ore. The great majority of the pyrite is present as irregular masses or as euhedral to subhedral crystals which were deposited on sphalerite layers in fissures or as replacements of sphalerite (figure 1A). In some places pyrite has been fractured and the fractures filled with sphalerite similar in every respect to the primary vein sphalerite. These relations indicate the deposition of pyrite both prior to and after the formation of some of the sphalerite.

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[8] Butler, R. D., Mylonitic Sphalerite from Friedensville, Pa. Abstract, *Am. Mineral.*, vol. **20**, p. 203, 1935.

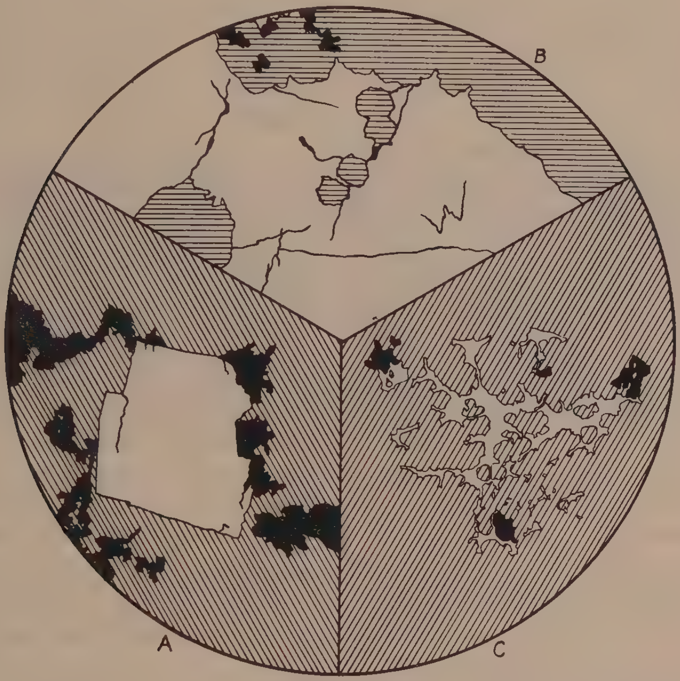

Fig. 1. Sketches traced from photomicrographs of polished surfaces showing the relations of pyrite (unruled), sphalerite (ruled) and carbonate and silica (black). A. Pyrite replacing sphalerite. B, C, Sphalerite replacing pyrite, leaving in "C" only the skeleton of a former grain. Magnification 40×.

Another relationship between sphalerite and pyrite, an unusual one, is found in the fine-grained chert-like sphalerite (figures 1B, 1C). Here pyrite crystals show numerous included circular areas of sphalerite and equally abundant concave-inward protuberances of sphalerite into the pyrite. In places the sphalerite has so nearly eliminated the pyrite that the remnant of the latter closely resembles, in plan, the connected aretes of mountain cirques.

Furthermore, between crossed nicols the circular areas of sphalerite within the pyrite, near their borders, have a more grayish color than the remaining part. This grayish zone fades gradually in passing toward the center of each patch, and commonly has a rude radiating appearance from the less affected center to the more grayish outer zone which is in contact with pyrite.

These relationships are interpreted as evidence of the encroachment and replacement of pyrite by sphalerite. The grayish zone bordering the circular sphalerite areas may well indicate the area of sphalerite still containing some dissolved iron sulphide either in solid solution or as submicroscopic disseminated inclusions.

This relationship may be similar to that described by N. W. Buerger[9] between sphalerite and chalcopyrite where the latter is thought to have been dissolved in the former. In any event, this grayish zone differs from the central part. Since the sphalerite areas are undeformed and the surrounding pyrite is undisturbed, structural differences are eliminated and a compositional difference is favored.

Marcasite has been reported as occurring at Friedensville but to the writer's knowledge marcasite has never been definitely determined by *x*-ray analysis, polished surface examination or chemical analysis. Two specimens of iron sulphide were submitted to Dr. H. V. Anderson for *x*-ray examination. One of them had a crude radiating structure and was associated with similar material showing marked decomposition. This material was thought to be more likely marcasite than pyrite and in the past has been so named. The second specimen was part of a typical cube of pyrite. Both were found to be pyrite.

MICROSCOPIC EVIDENCE OF CONDITIONS OF PRIMARY REPLACEMENT

Fibrous and mosaic quartz in some specimens replaces the limestone, and in other places fibrous quartz is the vein material cutting both sphalerite and pyrite, and in still other cases fibrous and mosaic quartz is replaced by pyrite and (or) sphalerite.

Much of the sphalerite replacing limestone is present in irregular masses but in places subhedral grains showing zonal growth are observed (figure 2). These have small arm-like projections reaching into the limestone from the solid sphalerite. These projections may join and form an irregular network around the solid limestone core. They are the evidences that the zinc sulphide solutions failed before the inter-arm areas could be completely replaced. The zoning is probably due to unequal distribution of inclusions some of which were very likely derived from the replaced limestone.

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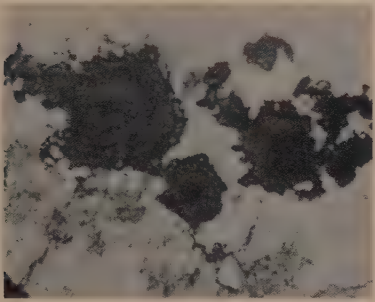
[9] Buerger, N. W., The unmixing of chalcopyrite from sphalerite: *Am. Mineral.*, vol. **19**, no. 11, pp. 525–530, 1934.

The grains of the limestone are normally clouded by numerous inclusions of carbonaceous matter, clay minerals and sericite. Where cut by veinlets of quartz, the carbonate adjacent to the introduced material has recrystallized and has eliminated the inclusions (figure 3).



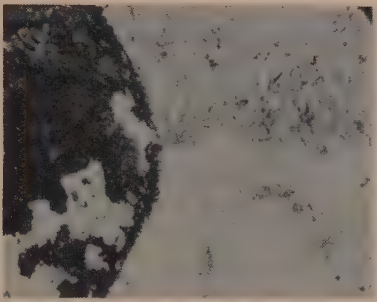


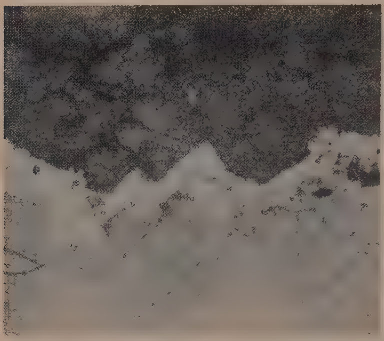
Fig. 2. Zoned crystals of sphalerite metasomatically replacing a fine grained limestone containing areas of mosaic quartz. Note the lace-like margins and the projecting nodes showing the incomplete development of the crystals. Magnification 120×.

Fig. 3. Silica solutions have entered the lower right part of the field depositing quartz and recrystallizing the limestone. Sphalerite has later replaced both quartz and carbonate. Magnification 120×.

Such inter-relationships together with those indicating no absolute priority of deposition of sphalerite or pyrite might indicate the ore forming solutions were silica-bearing and at the same time carried iron and zinc sulphides. An alternative explanation would be the postulation of a changing composition of the invading solutions. Radical changes in the composition of invading solutions may not be easily accepted but one might well imagine the earliest liquid to be more siliceous and therefore depositing silica dominantly, while later sphalerite might be the active replacing material from a solution richer in zinc sulphide than the first. The importance of solutions of changing composition as a cause of banding in veins is questioned by B. M. Shaub.[10]

In the case under discussion, however, the writer is inclined to think a change in the composition of the invading solutions most easily explains the replacement of limestone in one place by silica and in an adjacent area by sphalerite. Also, sphalerite is found in some instances to encroach, by replacement, upon both the limestone and quartz which itself had previously replaced limestone.

It is interesting to note that often a cleaner, purer zone of carbonate lies immediately in front of the encroaching sphalerite (figure 4). In other places a much darker narrow zone (figure 5) of material lies adjacent to the sphalerite. In the former case the structure of the original limestone and the cleaner zone is the same. Some larger grains may even be partly clear and partly clouded, and extend from the original into the altered rock. This cleaner zone is thought to have been formed by the diffusion of solutions through the carbonate which removed soluble inclusions or filled openings, either or both of which may have caused the darker color. This zone is not dominantly due to recrystallization because then one would expect it to have a structural break with the original mass.



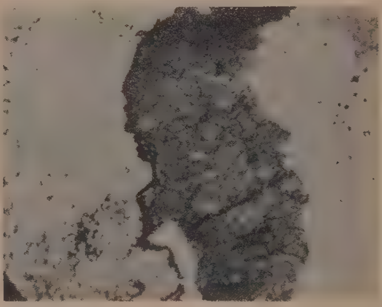


FIG. 4. Sphalerite replacing limestone. A cleaner zone has been formed just ahead of the sphalerite by the removal of soluble inclusions or the filling of openings in the carbonate. Magnification 160×.

FIG. 5. Sphalerite deposited in the space from which limestone has been dissolved. The dark band between sphalerite and limestone made up of the accumulated carbonaceous inclusions from the latter indicates that here metasomatic replacement was absent. Recrystallized calcite forms the material to the right. Magnification 120×.

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[10] Shaub, B. M., The cause of banding in fissure veins: *Am. Mineral.*, vol. **19**, pp. 393–402, 1934.

The dark band adjacent to the sphalerite in some of the specimens is formed by the accumulated inclusions removed from the limestone. Some of this material is incorporated within the zinc sulphide but much of it is pushed ahead of the mass. We must infer from this that in these places there was hindered circulation, or else that materials were introduced and removed by diffusion and hence discrete particles could not be carried. Their concentration in an advanced zone however necessitates the suggestion of the presence of a small amount of liquid ahead of the sphalerite, otherwise all inclusions from the limestone would be contained in the sulphide.

Conclusions Regarding Conditions of Primary Replacement

We may conclude that silica solutions, later richer in sulphides, invaded the limestone. Quartz first intimately replaced the limestone and was deposited in veinlets; later, sphalerite replaced the carbonate and in places quartz. This was accomplished through two processes: first, by metasomatic replacement evidenced by small sphalerite arms or veinlets penetrating carbonate grains, and second by simple solution and deposition. By this is meant the dissolving of a discrete part of the limestone and the subsequent deposition of sphalerite from solution. This latter process is thought to have resulted in the concentration of the dark band of inclusions discussed above. These inclusions were carried along by the solution which on one side of the inclusion band dissolved carbonate and on the other side deposited sphalerite.

Much of the primary sphalerite is found as vein and cavity fillings where replacement was at a minimum.

Secondary Minerals. The most abundant secondary ore mineral is calamine, although smithsonite and sphalerite are also present. Associated minerals in the oxidized ore are limonite, greenockite, quartz, calcite, dolomite, melanterite, and probably goslarite.

Calamine characteristically occurs in porous masses built up of successive irregular spongy encrustations of calamine chiefly but also containing some smithsonite and secondary sphalerite.

Above the water-table in places sphalerite has been protected by a layer of quartz which in turn has been coated by calamine. In thin-section a contact zone of calamine and quartz showed the following relations (figure 6). An euhedral crystal of quartz containing numerous smaller dust-like inclusions (probably chiefly carbonaceous matter from the limestone) exhibits an outer zone about .15 mm. thick in which mineral inclusions of calamine and carbonate grains from eight to ten microns in diameter are distributed. The interior limit of these is sharply defined and is a line parallel to the trace of the face of the crystal in which they are found. Calamine deposited on the quartz crystal has in places penetrated and replaced the silica to a depth of .03 mm. to .08 mm.

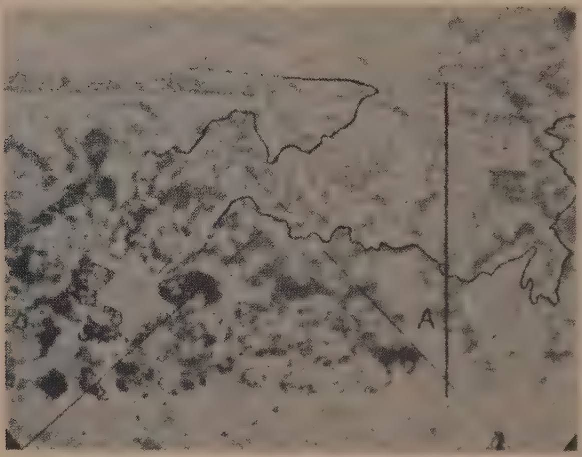

Fig. 6. Calamine replacing quartz. The quartz crystal shows an outer zone (A) of numerous inclusions which extends below the depth of calamine replacement and indicates the incorporation of the inclusions during the growth of the crystal. Magnification 215×.

We may infer from the above that the solutions depositing silica at first contained in suspension dust-like particles of other materials, while later larger fragments of calamine and calcite probably loosened by some minor movement were included in the silica as it was deposited. Following the deposition of quartz, zinc-bearing solutions entering the channels caused the partial replacement of quartz by calamine and elsewhere deposited a coating of the latter mineral.

Calamine in thin-section possesses strong relief in contact with quartz and balsam. It occurs in radiating and sheaf-like aggregates and as granular masses. Single larger crystals sometimes show a great number of yellow to red-brown granules as inclusions. These are thought to be greenockite but may be in part iron oxide.

Smithsonite is found intimately mixed with calamine in the highly porous vein and solution cavity fillings. It also forms drusy surfaces on the walls of joints or other openings and with other oxidized ores replaces limestone. It is less abundant than calamine.

Sphalerite in the oxidized ore is found with calamine and smithsonite on drusy surfaces, in porous masses encrusting surfaces and filling cavities and as a replacement of limestone. In thin-section, as stated above, it is brown to yellow or in some cases grayish in color but is distinctly lighter than the dark gray to black zinc sulphide of the primary ore. As has been discussed, it is thought that this lighter color is due as much to the greater freedom from fractures and inclusions as to the lower iron content.

Greenockite is found as a yellow dusty deposit on the surface of fractures or as aggregates of minute grains deposited along sheer planes in the limestone. It is thought to be one of the minerals appearing as inclusions in sphalerite and calamine.

Under the microscope the fine-grained, dusty greenockite is yellow to red-brown in color and has very strong relief. Individual granules are rarely more than a few microns in diameter and only the larger ones show double refraction. Aggregates of several hundreds of these granules are nearly opaque to transmitted light and except for their higher index of refraction closely resemble aggregates of limonite granules.

Melanterite occurs as a bluish-green to white earthy coating associated with weathered pyrite. Under the microscope it appears as fibrous and granular masses which are colorless and have a low index of refraction and weak birefringence.

Goslarite has been reported in the oxidized ore. A white deposit found on a smithsonite surface and thought to be goslarite is not readily identified. Further work will be done on this material.

NOTES AND NEWS

DICKITE FROM PENNSYLVANIA

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The Pennsylvania State College, State College, Pa.

It is the purpose of this paper to record two new localities for the rather rare mineral dickite, and to summarize its optical, chemical, and x-ray data.

The material, first examined, came from the coal workings at the Pine Knot Colliery in Schuylkill County, Pennsylvania, and was supplied to the writers by Mr. Charles K. Graeber of the Pennsylvania State Geological Survey. Sometime later Mr. J. R. Jones visited the locality at the request of the senior author and obtained several pounds of well crystallized material which proved to be very suitable for study. The data assembled from an investigation of this material indicate that the mineral is, without doubt, dickite. Some months after the occurrence of dickite was known at Pine Knot Colliery, a small pocket of white glistening material was discovered in a coal mine at the Colonial Colliery of the Maderia Hill Coal Company at Natalie, Pennsylvania. Mr. Edward G. Fox, in charge of mine operations there, very kindly supplied the writers with some of this material for investigation. Strangely enough, this proved to be dickite also. It is, however, unfortunate, that the occurrence at Pine Knot Colliery became flooded before the geology of the deposit could be studied, and equally regrettable that the deposit at Natalie, Pennsylvania, being only a small pocket, was completely mined out shortly after its discovery.

The dickite from Pine Knot Colliery occurs, for the most part, as a white glistening powder or small lumps composed of transparent tabular monoclinic crystals, often of exceptional beauty, varying in size from .1 to .5 mm. along the major axis. The crystals occur as individuals and in book-like groups, some of the latter often showing a radial arrangement. Parallel growths are apparently common, other groupings suggest a small angle of rotation with respect to adjacent plates; the angle, however, is not constant and probably represents mechanical displacement of lamellae in many of the complex groupings. In habit the crystals are well developed as pseudo-hexagonal plates flattened parallel to the base along which plane the mineral appears to break with ease. Some of the larger crystals, however, reveal very clearly the development of pyramidal faces. Although the material is generally white, some portions of the powder are light yellow to amber in color, and occasional lumps are distinctly orange, but since there is no appreciable change in refractive index with change of color it is believed that the coloration is due to iron stain and not to iron in solid solution. Of the associated species clear transparent quartz is most common, although a very small amount of pyrite and magnetic material are present. The quartz crystals are everywhere completely coated with dickite which impregnates the crystal surfaces in a manner suggestive of replacement. This, in itself may suggest a hydrothermal genesis for this mineral, but when considered in the absence of other evidence does not seem convincing. The physical properties of the dickite from Pine Knot Colliery as given above apply also to the dickite from Natalie, Pennsylvania, except that the mineral from the latter locality is finer grained.

The optical properties, determined from the larger crystals, agree with published data.[1] The book-like groups show the Bx_a interference figure with a fairly large 2V. The optical sign is positive. The extinction angle measured on the Bx_a section (010) is about 16° and may be considered one of its most diagnostic properties. The indices of refraction, determined by the oil immersion method, are as follows: $\alpha = 1.560$, $\beta = 1.562$, $\gamma = 1.566$.* The double refraction is therefore weak, yielding gray to yellow interference tints when the larger individual crystals are properly mounted and examined with a microscope. Some of the book-like groupings,

ANALYSIS[2] OF DICKITE FROM PINE KNOT COLLIERY, SCHUYLKILL, CO., PA.

	COMPOSITION	THEORETICAL COMPOSITION	MOL. RATIOS	
SiO_2	46.14%	46.55%	1.98	2
Al_2O_3	39.61	39.49	1.00	1
Fe_2O_3	—	—		
MgO	N.D.	—		
CaO	N.D.	—		
H_2O+	13.91	13.96	1.99	2
Total	99.66%	100.00%		

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[1] Ross and Kerr, *U. S. Geol. Survey, Prof. Paper* **165-E**, pp. 158–161.

* The values for the indices of refraction were obtained with the oil of immersion method, using white light, and therefore probably not more accurate than ±0.003.

[2] Brady, G. A., Analyst, Min. Ind. Exper. Sta., The Pennsylvania State College.

however, show an anomalous blue interference color and are positive in elongation.

The specimen used for chemical analysis was taken from a coal mine in Schuylkill County, Pennsylvania, and was prepared by sieving through 65 mesh on to 100 mesh screen in order to bring together the larger crystals. This material was then sorted carefully beneath the binocular microscope and a superior sample obtained. The chemical analysis is given on the preceding page.

This analysis may be reduced to a formula which compares favorably with the accepted one, $2H_2O \cdot Al_2O_3 \cdot 2SiO_2$. Since the silica is so slightly below the 200:100 ratio of silica to alumina accepted for this mineral, and the fact that only superior crystals were employed for the chemical analysis, it is believed the material from this locality occurs in unusual purity.

X-RAY IDENTIFICATION

For the purpose of the *x*-ray study a fine powder spectogram of the specimen was taken using copper radiation, no attempt being made to separate the K_β radiations. The specimen was mounted on a copper wire, the resultant copper lines serving as a method for the calibration of the film. The camera radius was 57.65 mm.

Table 1 shows the results of the *x*-ray analysis compared with reported data for dickite, kaolinite, and nacrite. The agreement with Gruner's values for dickite is good, with the possible exception of the lines adjacent to the primary beam. This may be accounted for in the correction of the film as there are no lines for copper in this region, and the correction curve must be extrapolated to include this area. A slight change in *l* when *l* is small makes a very noticeable change in *d*. The *x*-ray and optical data are, therefore, in agreement concerning the identity of the mineral dickite.

TABLE 1

A		B		C		D		E	
I	*d*	*I*	*d*	*I*	*d*	*I*	*d*	*I*	*d*
5	7.14^β	5	7.14^β			5	7.06^β	10	7.078
8	6.88	10	7.12			10	7.06		
								1	4.895
1	4.29^β								
3	4.33	4	4.43	8	4.471	6	4.32	8	4.404
		3	4.15	5	4.201	3	4.14	3	4.126
1	3.79^β					4	3.96		
8	3.77	5	3.95	5	3.846			2	3.928
		0.5	3.79			4	3.71		

TABLE 1—(*Continued*)

A		B		C		D		E	
I	*d*	*I*	*d*	*I*	*d*	*I*	*d*	*I*	*d*
10	3.52	10	3.578	9	3.631	10	3.54	9	3.579
				2	3.491				
		0.5	3.439					1	3.442
				0.5	3.336	0.5	3.33		
				0.5	3.161				
		0.5	3.011			0.5	3.07	1	3.042
				2	2.981	1	2.817		
				2	2.741	1	2.755	2	2.690
0.5	2.66	1–2	2.634						
		1	2.567$^{\beta}$						
0.5	2.59	3–4	2.566	5	2.591	5	2.556		
		1	2.524$^{\beta}$			several lines		1	2.537
2	2.48	4	2.514	8	2.526	5	2.491		
				1	2.408			10	2.418
								1–2	2.393
1	2.37	5	2.384			2	2.373		
2	2.28$^{\beta}$					8	2.341		
6	2.31	5	2.328	10	2.346			1	2.319
						5	2.272	0.5–1	2.263
0.5	2.19	0.5	2.180	2	2.225	0.5	2.200		
		0.5	2.099					1	2.069
1	1.97	4	1.976	8	1.995	4	1.983		
						1	1.930		
				1	1.910			2–3	1.902
		0.5	1.895			1	1.893		
				2	1.870				
						2	1.839		
		1	1.819	1	1.800				
0.5	1.78	3	1.792			1	1.785	1	1.795
		0.5	1.718					0.5	1.744
								2	1.675
6	1.64	4	1.649	9	1.659	7	1.658	2	1.649
						several lines			
						4	1.610	2	1.616
1	1.55	3	1.555	5	1.564	1	1.585	1	1.583
						3	1.536		
3	1.48	5	1.490	8	1.494	8	1.486	8	1.486
1	1.45	2	1.455	2	1.469	2	1.452	4	1.455
		2	1.431	0.5	1.434	1	1.430	0.5–1	1.434
0.5	1.39	1	1.391	1	1.409	0.5	1.389		
		1	1.374	1	1.383	0.5	1.371		
						3	1.340	1–2	1.358
5	1.31	4	1.317	8	1.323	4	1.306	0.5	1.314

A. Dickite from Pine Knot Colliery, Schuylkill Co., Pa.

B. Dickite from National Bell Mine, Red Mountain, Colorado, after J. W. Gruner "The Crystal Structure of Dickite" *Zeit. Kryst.*, (A), Bd. **83,** Heft 5/6, 1932.

C. Dickite from National Bell Mine, Ouray, Colorado, after C. S. Ross and P. F. Kerr "The Kaolin Minerals" **165–E,** *U.S.G.S.*, Prof. Paper, 1932.

D. Kaolinite from subway tunnel at Brooklyn, N. Y. After J. W. Gruner, "The Crystal Structure of Kaolinite," *Zeit. Kryst.*, (A) Bd. **83,** Heft 1/2, 1932.

E. Nacrite from Brand, Saxony, after J. W. Gruner, *Zeit. Kryst.*, (A) **85,** 345–354, 1933.

A PETROGRAPHIC USE OF FLUORESCENCE

Alonzo Quinn, *Brown University, Providence, Rhode Island.*

The use of fluorescence in determining the relative abundance, distribution, and textural relationships of minerals which are not readily distinguished in ordinary light is not new. So far as the writer is aware, this has been applied mainly to mineralogy rather than to petrography. The purpose of this short paper is to call attention to one rather specialized use of this method in petrography and to describe briefly how photographs of fluorescent minerals may be taken to show petrographic relationships that would hardly be possible in ordinary light.

The writer is engaged in a study of the rocks of Red Hill, N. H., among which is the interesting nephelite syenite, or foyaite, described by Pirsson.[1] Because of the great variation shown by different thin-sections of this rock from the same or nearby localities an attempt has been made to study the relationships of the minerals in large specimens. To accomplish this purpose satisfactorily it is desirable to be able to distinguish at a glance as many of the main constituents as possible. Macroscopically, the rock is composed of potash feldspar, nephelite, sodalite, and hornblende. The hornblende, of course, is easily distinguished from the rest of the minerals. The feldspathoids are different from the feldspar by possessing a more greasy luster, but that distinction is not sufficiently marked so that one can see readily the existing relationships. On certain exposed surfaces the feldspathoids have weathered in such a manner as to leave pits which make the relationships rather apparent. The distinction between the nephelite and the sodalite is hardly possible to the unaided eye, however. Progress towards making this distinction was made when it was discovered that certain specimens of nephelite syenite contain grains that fluoresce in an orange-red color when exposed to a mercury vapor tube. Further study has revealed that the fluorescent material was not nephelite, as had been suspected, but sodalite. That made it possible to trace very readily certain petrographic relationships, because a large number of specimens could be examined in a very short time. Thus, it became apparent immediately that sodalite is an irregular, but much more abundant constituent than had been supposed: Pirsson had stated that the rock contained about five per cent of sodalite.[2] Different parts of the same specimen may contain widely varying amounts of sodalite and the size of the grains varies greatly in different specimens and even in the same specimen. It became obvious that any one thin-section would probably not be representative. This method is of little use for weathered specimens, however, for the weathered surfaces of sodalite grains fluoresce not at all, or possibly in a faint greenish color.

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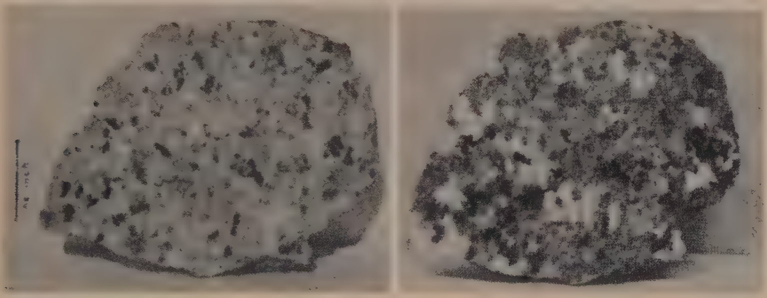
[1] Pirsson, L. V., and Washington, H. S., Contributions to the Geology of New Hampshire, no. III, On Red Hill, Moultonboro: *Am. Jour. Sci.*, vol. **23** (4th series), pp. 266–274, 1907.



A B

Fig. 1

A. Nephelite syenite in white light.

B. Nephelite syenite (same specimen as A) in ultraviolet light. White is fluorescent sodalite. Black is hornblende. Gray is feldspar and nephelite.

The fluorescence of sodalite in this rock is an aid not only to the student handling the rocks in the laboratory, but it also adds to the possibilities of demonstration to others, through photographs showing the relationships of this one constituent. The accompanying photographs are of the same specimen, one taken in ordinary white light and one in ultra-violet light. They show very clearly the relationships of three groups of constituents: (1) the hornblende in black, (2) the sodalite in white, and (3) the feldspar and the nephelite in gray. As yet, no method has been discovered for distinguishing clearly the nephelite from the feldspar, although B seems to show the nephelite in a darker gray than the feldspar and certain enlargements of this picture make this distinction slightly more pronounced.

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[2] Pirsson, L. V., and Washington, H. S., *loc. cit.*, p. 272.

An extensive study of the possibilities of obtaining photographs of this sort has not been made, but one fairly successful method for this particular set of rocks was developed. It is, herewith, described briefly. "Defender X-Fast Panchromatic" film was used. Much of the violet and ultra-violet light was filtered out by filters of the type described in this journal by Stephens.[3] The equivalent of two "G" or "Wratten 16" filters and one filter composed of four sheets of red cellophane were placed over the lens of the camera. The exposure time was forty-five minutes and the aperture was set at F-16. Other procedures might prove equally or more successful for this particular rock. Other rocks would almost certainly demand different methods because of varying colors and intensities of light.

It is not expected that this use of fluorescence will become general, for only a few rocks or mineral assemblages show relationships clearer under ultra-violet light than in white light. Not all nephelite syenite rocks have fluorescent constituents and not all sodalite fluoresces. It is expected that other special uses such as herein described will be found and that occasionally the method will have considerable value.

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[3] Stephens, Maynard M., Photography for the mineralogist: *Am. Mineral.*, vol. **18**, pp. 253–254, 1933.

THE SIZE OF CRYSTALS

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In a recent paper, Palache[1] has given the dimensions of a number of large crystals of various minerals and has directed attention to the problem of the genetic factors that influence their growth. It would appear that a growing crystal would increase in size indefinitely if a continuous supply of material were brought to its surface. However, experiment has shown that growth may cease with the attainment of a critical size, regardless of the amount of material still available. Retgers[2] concluded that there is a distinct maximum in size for every crystal, varying somewhat with the conditions, beyond which it is incapable of further growth. Von Hauer[3] earlier observed that there is a certain limit to growth beyond which the crystals become markedly imperfect, developing a composite and fissured structure with surface excrescences and cavities. This limit was found to vary for different substances and under varying circumstances. A similar observation was made by Ord[4] for crystals of calcium oxalate and the phenomenon was likened by him to the property of liquids to form drops, but only drops of a certain limit of size for each kind of liquid.

Both Retgers and von Hauer found that upon addition of a small amount of a foreign substance, such as a metallic chloride or an acid, to the crystallizing solution the crystals resulting could grow perfectly to much larger sizes. In addition to the citations of these workers on this effect there may be mentioned the observations of Buchner[5] on the property of Mg, Cu and Fe chlorides to perfect and enlarge NaCl, KCl and NH_4Cl crystals; of Gibbs and Clayton[6] on the similar effect of lead salts on NaCl; of Ehrlich[7] on the remarkable action of pectin in inducing such changes in NH_4Cl and other salts; and of Yamamoto[8] on the effect of a large number of metallic salts on the size and transparency of NaCl, KCl and NH_4Cl crystals. Addition of the foreign substance is frequently found to be accompanied by a change in crystal habit; borax, for instance, inducing the development of hemimorphic faces on magnesium sulphate in addition to perfecting the crystals (von Hauer).

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[1] Palache, C., The largest crystal: *Am. Mineral.*, vol. **17**, pp. 362–363, 1932.

[2] Retgers, J. W., Ueber den Einfluss fremder Substanzen in der Lösung auf die Form, die Reinheit und die Grösse der ausgeschiedenen Krystalle: *Zeit. physik, Chem.*, vol. **9**, p. 278, 1892.

[3] Von Hauer, K., Krystallogenetische Beobachtungen: *Verh. der k. k. Geol. Reichsanst. Wien*, pp. 45, 57, 75, 90, 162, 296, **1877**; pp. 185, 315, **1878**; pp. 20, 181, **1880**.

[4] Ord, W. M., On the influence of colloids upon crystalline form and cohesion. *London*, **1879**, p. 125.

[5] Buchner, L. A., Ueber die Bildung durchsichtiger, dem Steinsalze ähnlicher Salzwürfel: *Jour. prakt. Chem.*, vol. **111**, pp. 259–266, 1871.

[6] Gibbs, W. E., and Clayton, W., The production of large, clear cubical crystals of sodium chloride: *Nature*, vol. **113**, pp. 492–493, 1924.

Zwicky[9] has suggested in explanation of the phenomenon of size limitation in ordinary growth that the liberation of heat of crystallization or heat of fusion at a growth surface may cumulatively produce, through thermal stresses, a disordered mosaic surface which, at the attainment of a critical size, may become such as to prevent further growth. The observation of Stöber,[10] that large perfect crystals can be obtained from a melt by placing the axis of greatest heat conductivity of the crystal in the direction of heat flow, is of significance in this connection. W. H. Bragg has suggested that the regular fitting of molecules into a crystal may begin correctly enough, in the nuclear stage, but that errors of adjustment may creep in until the surface becomes somewhat disordered, and growth ceases because fresh molecules cannot slip into their proper places.[11] Von Hauer observed that the heterogeneous surface occurring at the maximum size is marked by a difference of angles in the composite parts, and said that a crystal may bear in itself a tendency to irregularity which becomes more conspicuous with continued growth. Retgers believed that the tendency for a size maximum is a property of the crystal itself and that its cause can not be sought in the properties of the solution.

Foreign substances apparently increase the transparency and perfection of crystals, and induce a larger size, by decreasing the

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[7] Ehrlich, F., Ueber die Beeinflussung des Krystallwachstums von Salmiak durch Pektin: *Zeit. anorg. Chem.*, vol. **203**, pp. 26–38, 1931.

[8] Yamamoto, T., *Bull. Inst. Phys. Chem. Res. Tokyo*, vol. **10**, pp. 52–60, 679–686, **1931**; vol. **11**, pp. 1083–1097, 1932.

[9] Zwicky, F., Secondary structure and mosaic structure of crystals: *Phys. Rev.*, vol. **40**, p. 74, 1932.

[10] Stöber, F., Kunstlicher Darstellung grosser, fehlfreier Kristalle: *Zeit. Kryst.*, vol. **61**, p. 299, 1925.

[11] Bragg, W. H., Cohesion and molecular forces: Alexander's *Colloid Chemistry*, vol. **1**, p. 266, 1926.

tendency for a mosaic structure, as was suggested by Oka,[12] for micro-composite NaCl crystals, but in what manner this would be accomplished is not evident. Slow growth, in general, enhances the size and perfection of crystals, as was brought out in this connection by Zwicky, and the effect of adsorbed foreign substances may possibly be by slowing up growth. This view is supported by the frequent occurrence of habit modification in such cases, and is not inconsistent with the fact that under other circumstances addition agents may cause the formation of fine grained aggregates or of skeletal growths, in place of normal crystals, as a result of an extreme hindering of growth.

The effect of magma-derived mineralizers in promoting crystal growth in certain geological processes may also include an action on the coarse structure of the crystals, of the nature described, in addition to the viscosity and chemical control that is generally ascribed to them.

A number of large crystals that have come to the attention of the writer are cited in the following table. The specimens are contained in the collection of The American Museum of Natural History, unless otherwise stated. Further instances have been mentioned by Spencer.[13]

SPECIES	LOCALITY	DESCRIPTION
Analcite	Fassathal, Italy	Trapezohedron; $a=7$ cm.
	Cape Blomidon, N.S.	Trapezohedron, implanted and distorted; longest dimens. $=11$ cm.
Apophyllite	Poonah, India	$c=6$ cm., $a=7$ cm.
Aragonite	Cianciana, Sicily	Pseudo-hexagonal twin, implanted; $c=$ about 4 cm., distance across base $\perp$ to side $=8$ cm.
	Girgenti, Sicily	Pseudo-hexagonal twin· $c=5.5$ cm., distance across base $\perp$ to side $=5.5$ cm.
Axinite	Japan	8 cm. along (110) (1$\bar{1}$1) edge (Takimoto).
	Medels, Switzerland	Elongated bent composite crystal; $b=9$ cm.
Bournonite	Neudorf, Germany	Tabular; $6\times6\times2$ cm.
	Cornwall, England	Implanted distorted twinned crystal; longest dimens. $=6.5$ cm., $c=2.5$ cm.

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[12] Oka, S., On the opacity of sodium chloride crystals: *Jour. Soc. Chem. Ind. Japan*, Supplem. Binding, vol. **35**, pp. 178–179, 1932; vol. **36**, pp. 141–143, 144–145, 1933.

[13] Spencer, L. J., Large specimens of spar from the Snailbeach Mine, Shropshire: *Nat. Hist. Mag. Brit. Mus.*, vol. **1**, p. 259, 1928.

SPECIES	LOCALITY	DESCRIPTION
Brookite	Magnet Cove, Arkansas	Stout pyramidal crystal; $c=12$ cm. Another specimen is a fragment of a much larger crystal.
Brucite	Texas, Pennsylvania	Merged crystal; 14×8×1 cm. Also a cleavage surface with longest dimens. =19 cm.
Calcite	Joplin, Missouri	Scalenohedron, one end implanted; $c=85$ cm. (meas. length.)
Cerussite	Dundas, Tasmania	Thick rounded prism; $c=12$ cm.
	Nertschinsk, Urals	Thick tabular crystal; 7×3.5×2.5 cm.
	Broken Hill, N.S.W.	Thin prisms; c from 8 to 13 cm.
Datolite	Westfield, Mass.	Implanted distorted crystal; 7×5.5×5 cm.
	Osceola Mine, Mich.	Implanted distorted crystal; 5.5×5×4.5 cm.
Dolomite	Alexander Co., N.C.	Rhombohedron 10 cm. on edge (Hidden and Washington).
	Stony Point, N.C.	Distorted rhombohedron; 9.5×7×6 cm.
Epidote	Untersulzbachthal, Austria.	Prism, both ends broken off; 25×3×3 cm.
Erythrite	Schneeberg, Saxony	Radiating needles; $c=5$ cm.
Fluorite	Westmoreland, N.H.	Octahedron, green; 21 cm. on edge.
	Cumberland, England	Cube, violet; 24 cm. on edge.
	Cumberland, England	Cube, violet; 13.5 cm. on edge.
	Weardale, England	Cube, violet; 11 cm. on edge.
	Cornwall, England	Cube, yellow-green; 12 cm. on edge.
	Jefferson Co., N.Y.	Cube, green; 13.5 cm. on edge.
Galena	Pitcher, Oklahoma	Cube; 13 cm. on edge.
	Galena, Illinois	Cube; 13 cm. on edge.
	Galena, Illinois	Distorted cube; 21×4×4 cm.
	Galena, Illinois	Distorted cube; 13.5×5.6×3 cm.
	Joplin, Missouri	Cube; 14 cm. on edge.
Gypsum	Fremont River Canyon, Utah	Single cleavage surface; 102×51 cm.
	Fremont River Canyon, Utah	Prismatic crystal; 122×22×14 cm.
Halite	Stassfurt, Germany	Irregular cleavage fragment; longest dimens.=23 cm.
Hematite	Sussex Co., N.J.	Parting surface; longest dimens.=11 cm.
Ilmenite	Froland, Norway	Stout, merged crystals; longest dimens. =14 cm.
Leucite	Wiesenthal, Bohemia	Trapezohedron; $a=6$ cm.
	Rocco Montina, Italy	Trapezohedron; $a=5$ cm.
Magnetite	Twin Peaks, Millard Co., Utah	"even larger than 3 in. in diam." (Patton)
	Twin Peaks, Millard Co., Utah	Implanted octahedron; 9 cm. on edge.

SPECIES	LOCALITY	DESCRIPTION
Matlockite	Derbyshire	Flat broken fragment; longest dimens. = 10 cm.
Microlite	Amelia Court House, Va.	Octahedron; 6.5 cm. on edge
Monazite	North Carolina	$a=18.5$, $b=26$, $c=31.5$ cm. Wgt. = 58$\frac{3}{4}$ lbs. (Schaller).
Phosgenite	Monti Poni, Sardinia	Distorted crystal; 5×4×2.5 cm.
Pyrite	Leadville, Colorado	Cube; 16 cm. on edge.
	Rio, Elba	Octahedron; 8 cm. on edge.
	Brockville, Ontario	Octahedron; 7.5 cm. on edge.
	Rio, Elba	Pyritohedron; $a=13$ cm.
	Summit Co., Colo.	(210) Pyritohedron, implanted; 6.5 cm. on short edges
Pyrrhotite	Freiburg, Germany	$c=5$ cm., $a=10$ cm.
Quartz	St. Gotthard, Switzerland	Dark smoky; $c=45$ cm., $a=25$ cm.
	Auburn, Maine	Pale smoky, distorted and broken; $c=70$ cm., $a=34$ cm. (meas.)
	Thunder Bay, Michigan	Amethyst, implanted, no prism faces; rhomb. edge = 15 cm.
Rutile	Graves Mt., Georgia	Stout fourling, distorted; 11×9×7 cm. Another, part in matrix, has $c=13$ cm.
Scheelite	Japan	$c=33$ cm. (Wada).
Siderite	Pikes Peak, Colo.	Rhombohedron; 13 cm. edge.
	Carinthia	Composite rhomb., merged with others; 9 cm. on edge.
Spinel	Amity, Orange Co., N.Y.	"16 in. around base"; another crystal weighed 59 lbs. (Shepard).
Sulphur	Cianciana, Sicily	Broken crystal; 14×13×8 cm. (meas.)
Titanite	Eganville, Ontario	Wedge habit; 26×18×12 cm.
Witherite	Alston Moor, England	Rounded pyramidal crystal, incomplete; $c=8$ cm. (meas.) = 13 cm. (est. for ideal).
Zincite	Franklin, N.J.	Embedded formless single crystal; greatest dimens. = 5 cm. $\perp$ to cleavage and 6 cm. across cleavage.

PROCEEDINGS OF SOCIETIES

MINERALOGICAL SOCIETY OF GREAT BRITAIN AND IRELAND

MINERALOGICAL SOCIETY, *March 7*, Sir Thomas H. Holland, president, in the chair.

The following papers were read:

(1) The late Palaeozoic quartz-dolerites and tholeiites of Scotland. By DR. FREDERICK WALKER.

Dikes of these rocks and the related sills show marked resemblances both mineralogical and chemical to the Whin Sill, and appear to belong to the same period. Chemical analyses of an unaltered residual glass in one of the tholeiites shows it to be highly siliceous, and there is therefore no reason for considering the micropegmatite of the very similar quartz-dolerites to be other than magmatic. The origin of the suite is ascribed to mild contamination of the parental Carboniferous olivine-basalt magma through prolonged contact with the "sial."

(2) The role of kyanite in the "hornfels zone" of the Carn Chuinneag granite (Ross-shire). By Prof. C. E. TILLEY.

The hornfelses carry a garnet of almandine type ($Fe_{75}Mn_2$) and kyanite is developed as (1) replacement of chiastolite, (2) replacement of cordierite, (3) swarms of fine needles associated with biotite, and (4) coarser crystals in quartz-kyanite veinlets cutting the banding of the hornfelses.

(3) A critical review of the data for a revision of the enstatite-hypersthene series. By ROBERT WALLS (communicated by Prof. H. H. Read).

Many imperfections are found in the published data which have been used in constructing curves to show variations of physical properties with chemical composition. There is need for further analyses of optically investigated material. Four new analyses have been made and a corrected diagram showing changes of γ and 2V with the content of $FeSiO_3$ has been drawn.

(4) Two new bismuth minerals from South Africa. By Prof. E. D. MOUNTAIN.

A nodule of a pale grey mineral found with bismuth ores near a pegmatite outcrop 13 miles NW. of Jackals Water, near Steinkopf, Namaqualand, has a composition very nearly BiOCl. X-ray powder photographs of the material confirm its identity with artificially prepared BiOCl and distinguish it from the hydrated bismuth oxychloride, daubreeite. The new mineral, which it is proposed to name *bismoclite*, is tetragonal with cell-sides $a=3.89$, $c=7.37$Å. $H=2\frac{1}{2}$. Sp. gr. 7.36.

The other new mineral, *boksputite*, is opaque, pale yellow to grey-brown, and occurs in quartz-veins associated with wolframite, scheelite, and beryl on the farm Boksput, Gordonia. Its chemical composition is near $6PbO.Bi_2O_3.3CO_2$. $H=3\frac{1}{2}$. Sp. gr. 7.29.

The Department of Geology, Queen's University, announces the publication, of a set of mimeographed notes entitled "Introduction to Petrofabric Analysis" by H. W. Fairbairn. Approximately 125 pages with numerous figures, bound between loose-leaf board covers. Price $1.00 post paid, obtainable from the above address. Dr. Fairbairn has recently completed a two-year study of petrofabric methods in Innsbruck, Göttingen and Berlin.